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Souhegan River
Protected Instream Flow Report

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Introduction

This Protected Instream Flow (PISF) report represents the completion of Task 5 of the work schedule defined for the Instream Flow Studies and Water Management Plan for the Souhegan River Designated Reach. This report combines previous information describing the flow-dependent instream public uses, outstanding characteristics, and resources (IPUOCRs) with estimates of the flow needs for each of these IPUOCRs. IPUOCR categories include: recreation (boating and fishing); pubic water supply; pollution abatement; hydroelectric energy production; fish and wildlife habitat; aquatic and fish life maintenance and enhancement; rare, threatened and endangered species (RTE): fish, wildlife, vegetation and natural/ecological communities; and environmental/fish habitat. For each of these flow-dependent IPUOCRs, their location and protection goals are delineated as well as the methods used to determine these goals.

Part 1 of this report describes each IPUOCR and their respective flow goals. Part 2 of this report looks at these goals in light of the existing system hydrology and withdrawals in order to determine if, when and where PISF goals are not met.

To get to the final form of this report, it will first be presented to the Technical Review Committee and then the general public. Comments and questions on the report and its findings will be addressed and synthesized into the final version of this report.

Part 1. Locations and the Protection Goals for IPUOCR Entities

I.) Recreation

In both the Souhegan River Watershed Study (NRPC 1995) and the Souhegan River nomination report for state designation (SWA and NRPC 1999) boating and fishing were identified as recreational resources on the Souhegan River. In this study, both of these recreational uses are considered to be flow dependent resources. For boating recreation a PISF is proposed based on information obtained from recreational boaters, while fishing PISFs are addressed as part of the instream resources assessment later in this report.

As noted in the Souhegan River Watershed Study (NRPC 1995), boating recreational activities on the river are limited to canoes and kayaks with most whitewater paddling done in the Upper Souhegan River in the section from Greenville to Wilton and during the spring and other periods of high water. The Appalachian Mountain Club (AMC) River Guide (AMC, 2002) describes the Souhegan River as good intermediate whitewater in the upper portions (Greenville to Wilton) with a mixture of flatwater, quickwater, and short rapids sections in the lower portions from Milford to the Merrimack River. With the exception of the reach from the Turkey Hill Bridge to Merrimack, the river is characterized as boatable in high water. High water conditions most commonly occur in the spring with snowmelt (April) but may occasionally occur at any time of the year in response to a large rainstorms.

Consequently, this evaluation of protected flows focused on the upper portions of the Souhegan River since boating use is flow dependent there, but not so in the lower portion. No particular time of year was targeted since suitable boating flows can occur at any time of the year, although they are far less probable at times other than the spring.

Because acceptable boating flows vary due to different boating methods and skill levels, the development of PISF for boating recreation was based on the results of a limited survey of boaters. The survey included an interview of boaters in October 2005 following a large regional storm event. During the period of October 7-9, 2005 (Figure 1), eight to ten inches of rain fell on the watershed, increasing flows in the river from 27 cfs (0.16 cfsm), at the Merrimack gaging station on October 8 at 00:15, to a peak of 1,190 cfs (6.96 cfsm) on October 9 between 19:15 and 21:30.

Figure 1. View of the Upper Souhegan River looking upstream from Route 31 bridge, October 10, 2005.

A qualitative recreational survey was conducted between 12:00 and 15:00 on October 10, 2005 to determine recreational boating preferences. At 12:00 on October 10, flow had declined to 815 cfs (4.77 cfsm) and by 15:00 had declined further to 761 cfs (4.45 cfsm), Figure 1. A total of nine boaters were interviewed at the Route 31 River crossing in Wilton near the Greenville town line (Figure 2). Several other boaters were present, but were not interviewed. Eight of the boaters were kayakers while one was a whitewater canoeist.

The interviews were informal, but the following information was solicited:

- How often do you boat on the Souhegan?
- From where did you travel?
- How do you monitor flow conditions on the Souhegan River for this location?
- Which reaches of the river do you run?
- What is the best flow range to run?
- What is the minimum flow you would consider running?
- Can we contact you for a follow up?

Figure 2. Boating access point at Route 31 Bridge, Upper Souhegan River on October 10, 2005.

The individuals interviewed typically boated the river three to four times per year, although one respondent had not boated the Souhegan in 25 years and another ran the river 12 times a year. Many of those interviewed had been boating on the Souhegan for many years and had considerable experience on the river over a broad range of flow conditions.

The primary boating season is the spring during and after snowmelt and during other times of the year in response to major runoff events triggered by slow moving fronts or hurricane remnants. Most of the boaters had not been on the Souhegan since the past spring. Flow conditions suitable for whitewater boating on the Upper Souhegan River have been compiled from boaters' experiences by the American Whitewater Association (www.americanwhitewater.org) and are presented in Table 1. This information supports the results of the field interviews, which indicate that the greatest chance of finding the river runable is during spring high flows in March, April and May.

All of the boaters interviewed were from southern New Hampshire and northern Massachusetts with the furthest away traveling from Lexington, MA. The Souhegan can probably be categorized as a local to regional boating destination.

Table 1. Estimated percent chance of finding the Upper Souhegan River runable for whitewater boating.

Month	% Chance	Comment
January	5%	Usually frozen
February	10%	Usually frozen
March	40%	Opens up around mid-month
April	65%	Best chance in early April
May	20%	Best chance in early May
June	8%	No comments
July	5%	No comments
August	5%	Just a trickle
September	10%	Tropical storms and their remains
October	15%	No comments
November	20%	Fall rains, dormant trees
December	20%	River starts freezing about Christmas

Source: http://www.americanwhitewater.org/rivers/id/1185

Boaters monitored the flow conditions on the Souhegan with a variety of sources including, word of mouth, the USGS gage in Merrimack, two hand-painted gages on the upper reaches of the Souhegan, or a general knowledge of how the Souhegan compares to flows in other gaged rivers. Boaters also obtained information on conditions from the Merrimack Valley Paddlers webpage www.mvp.org , the American Whitewater Association webpage www.americanwhitewater.org and the Appalachian Mountain Club paddlers web page www.nhamcpaddlers.org A general frustration at the discontinuation of the gage on Stony Brook was voiced (since conditions there mirror the upper Souhegan better than the Merrimack gage) and a suggestion for a telemetered gage in the upper portion of the Souhegan was offered. It was generally believed that although there was a relationship between the reading at the USGS gage and the flows on the upper river, it was not always consistent particularly when flows were changing rapidly.

Once the boaters reach the river, the hand painted gages are the primary sources of flow information. One gage is on the downstream end of the concrete wall at the shorebank fishing access site in Greenville (Figure 3) and another is downstream of the Route 31 bridge and is visible from the bridge. The gages are marked in 0.5 foot increments, although there does not seem to be any direct relationship between the two gages. Guidance regarding gage readings and boatability has been summarized by the American Whitewater Association and is presented in Table 2.

Table 2. Runability of Upper Souhegan based on two hand-painted gages on upper river (Greenville and Route 31 Bridge).

Greenville Put-in (reading in ft)	Route 31 Bridge (reading in ft)	Runability
0.8	**1.3**	**Minimum play level at bridge hole**
0.9	**1.4**	
1.0	**1.5**	**Minimum level most people like**
1.2	**1.5**	
1.4	**1.6**	**Good surfing at ledges**
1.7	**1.7**	**Medium low**
1.9	**1.8**	
2.1	**1.9**	**Medium**
2.25	**2.0**	**Medium high**
2.4	**2.1**	**High**

Note: Above 2.1 feet at the bridge, the gage is not reliable because of flow velocity

Source: http://www.americanwhitewater.org/rivers/id/1185

At the time of the survey, the upper gage was at 1.5 feet while the Route 31 Bridge gage was at 1.4 feet. At the upper gage, boating is possible at gage readings of 1.0 feet and above although 1.5 feet was considered the minimum for some respondents. At a gage height of 2 feet, the conditions are considered good, at 2.5 even better (Table 2). At a gage height of 3 feet one respondent noted that the water was in the woods and he would not run it. Another responded that there was no upper limit.

It is worth noting that the gage reading was reported to be 2 feet on October 9, 2005 when the flow at the USGS gage downstream in Merrimack was 1,190 cfs (6.96 cfsm). Several boaters agreed that the minimum flow for boating was around 700 cfs (4.09 cfsm) at the USGS gage and the optimal was around 1,200 cfs (7.02 cfsm). Many stated that they would not consider running the river at flows lower than those at the time of the interview (760-815 cfs at the USGS gage). Two boaters related conditions to the gage height at the USGS gage indicating that a gage height of 4 feet (560 cfs or 3.27 cfsm) is marginal, the gage height on the day of the interview (October 10) of 4.7 feet (997 cfs or 5.83 cfsm) was acceptable, while a height of 6 feet (1,864 cfs or 10.9 cfsm) at the USGS gage was too high.

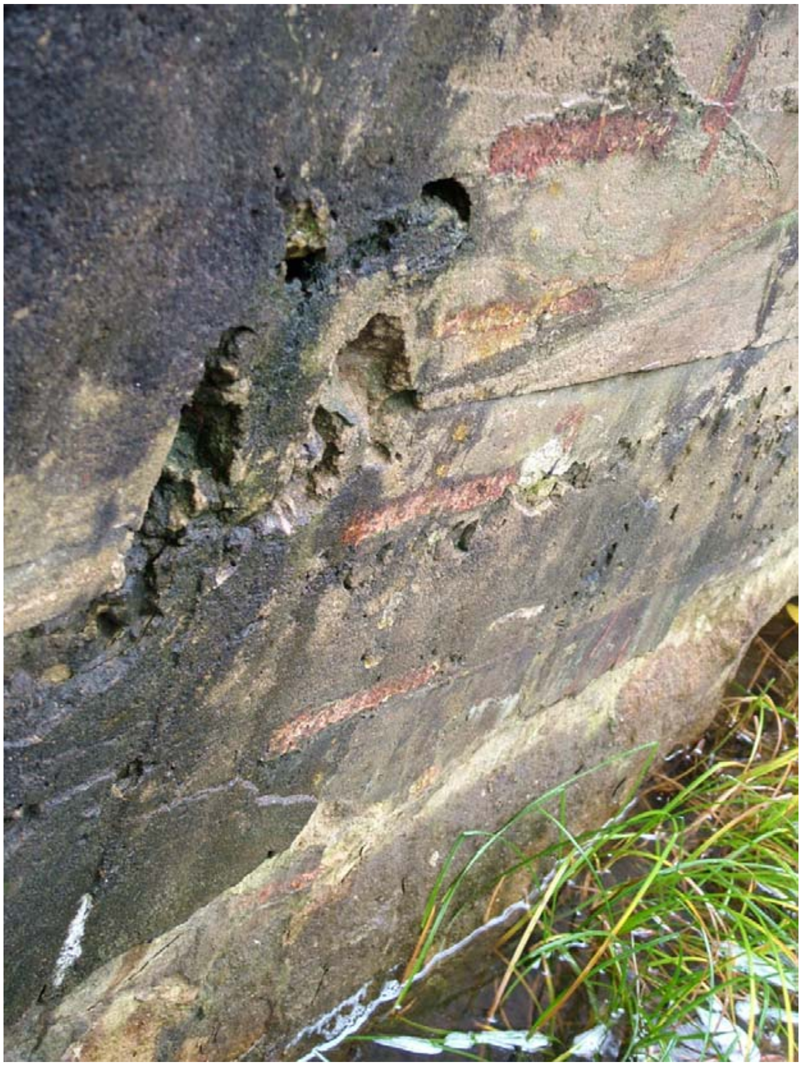


Figure 3. Hand painted gage at the shorebank fishing access on the Upper Souhegan River in Greenville, New Hampshire.

Based on available data in the form of the USGS stage-discharge relationship for the Souhegan gage in Merrimack, field observations of instream gage readings, anecdotal evidence provided by boaters, staff gage information provided by the American Whitewater Association, and the drainage areas for each of these locations; a relationship between the flows recorded at the USGS gage in Merrimack and the painted gages at the fishing access site and the Route 31 bridge was developed. Table 3 presents the gage reading/streamflow estimates for the three gages on the Souhegan.

The majority of the boaters on the river on October 10, 2005 were running the "steep" section of the upper river from the shorebank fishing access in Greenville to the Route 31 bridge near the Wilton/Greenville town line. Two boaters were running the river down to the Route 101 bridge in Wilton. It appeared from the group interviewed that the upper section of the river was the most popular for whitewater enthusiasts (Figure 4).

Table 3. Gage reading and streamflow correlations at the Greenville, Route 31 bridge and Merrimack gages.

Merrimack USGS Gage		Greenville Gage		Route 31 Gage	
Gage Height (ft)	Streamflow (cfs)	Gage Height (ft)	Streamflow (cfs)	Gage Height (ft)	Streamflow (cfs)
~4.0	~600	1.0	~120	~1.5	~220
~4.3	~800	1.5	~140	~1.65	~260
~5.0	~1,200	2.0	~240	~1.85	~450
~5.45	~1,500	2.5	~300	~2.15	~575
~6.0	~1,800	3.0	~360	Not available	~670

Whitewater boating on the Souhegan River is clearly a flow dependent resource (Figure 4). Successful running of the river requires flows above the average flow (Merrimack gage flow of 282 cfs or 1.65 cfsm). These flows are not expected to be influenced by many of the measures proposed as a part of the Water Management Plan (WMP). Should the WMP recommend flood skimming to put water into storage, the impact of these activities on whitewater boating will be evaluated further and more quantitatively. Metrics such as those presented in Table 1 will be used to quantify the potential impact of any proposed water management activities on this resource.

Figure 4. Boaters Downstream of Route 31 Bridge, October 10, 2005.

Flatwater boating, both upstream of the upper section (in Water Loom Pond for example) and most of the river downstream of Wilton is not flow dependent and therefore can occur during almost all open water time periods. As a result, no PISF is proposed for relative to this recreational boating.

II.) Fishing

The Souhegan River is a popular destination for recreational fishing. It is easily accessible by road, can be waded or fished from shore in most locations, and provides a variety of habitats for anglers to fish. Native fish species that may be targeted by anglers include:

- Atlantic salmon
- Brook trout
- Pumpkinseed
- Redbreast sunfish
- Yellow perch

Additionally, a number of species have been introduced and are now established within the Souhegan that are of interest to fisherman include:

- Largemouth bass
- Smallmouth bass
- Bluegill
- Black crappie

However, the majority of fishing on the Souhegan is aimed at stocked trout species. The New Hampshire Fish and Game Department (NHF&GD) regularly stocks trout into the Amherst, Greenville, Merrimack, Milford, New Ipswich, and Wilton sections of the Souhegan River. Brown and rainbow trout, two non-native species, along with native brook trout are stocked several times during each spring (April and May). Table 4 presents the 2004 stocking data for the Souhegan, which were obtained from the NHF&G's website (www.wildlife.state.nh.us/Fishing/fishing.htm).

In the Upper Souhegan River, the NHF&GD has implemented special rules for fishing on the reach located 300 feet upstream of the green bridge on Old Wilton Road in Greenville to a point 300 feet downstream of the Route 31 bridge in Wilton (NHF&GD 2006). In this reach there is no closed season for taking of all species, except for salmon or smelt. Although from October 16 through June 15, all fish caught must be immediately released and only barbless single hook artificial lures and flies can be used. For the remainder of the year (June 16 through October 15) fish can be taken by all legal methods with a daily limit for brook trout of five fish or five pounds.

Recreational fishing on the Souhegan River is a flow dependent resource. The protected instream flows that are required to maintain the environmental and fish habitat resource are those that will be adequate to preserve recreational fishing on the Souhegan River. The protected flows for fish habitat resources are discussed in Part 1, Section VII of this report.

Table 4. New Hampshire Fish and Game Department Stocking Records for the Souhegan River during 2004.

Total Fish Stocked in the Souhegan River - 2004				
Town	**Species**	**Age of fish**	**No. of fish**	**lbs of fish**
AMHERST	BT	1+YR	700	350
AMHERST	EBT	1+YR	650	305
AMHERST	RT	1+YR	780	780
GREENVILLE	EBT	1+YR	600	313
GREENVILLE	RT	1+YR	450	450
MERRIMACK	BT	1+YR	800	400
MERRIMACK	RT	1+YR	200	200
MILFORD	BT	1+YR	1,350	585
MILFORD	EBT	1+YR	820	425
MILFORD	RT	1+YR	1,125	1125
NEW IPSWICH	EBT	1+YR	600	300
NEW IPSWICH	RT	1+YR	750	750
WILTON	BT	1+YR	1,350	585
WILTON	EBT	1+YR	1,030	508
WILTON	RT	1+YR	975	975

BT – Brown Trout, EBT – Eastern Brook Trout, RT – Rainbow Trout

III.) Public Water Supply

Public water supplies (PWSs) located along the Souhegan River are dependent upon surface water or groundwater sources, with the later being the principal water supply source. The Town of Greenville is the only community that is currently dependent upon surface water as a supply source. Greenville's surface water source is not a direct withdrawn from the Souhegan River, but is an impoundment on tributaries to the Souhegan River. The Town of Greenville's water supply is the Tobey reservoir, which is located in Temple, NH just off of Route 45. The Tobey reservoir is a constructed impoundment on the divide of Temple Brook to the north and an unnamed tributary to the Souhegan River to the south. Temple Brook flows into Blood Brook in Wilton, which discharges into the Souhegan River near the Town of Wilton's Water Supply wells. The unnamed tributary flows to the south and discharges into the Souhegan River approximately 1.3 miles downstream of Greenville.

No direct diversion of water from the main stem of the Souhegan River is used by the Town of Greenville Water Works for the Tobey reservoir. The reservoir captures flow from two small drainages (Gambol Brook and an unnamed stream) located west of Route 45. Since there is no direct diversion from the Souhegan River to this water supply system it is not considered a flow dependent resource and no PISF is proposed. But since it is located within the WMPA, its impact on the PISFs established for the designated segment of the Souhegan River will be addressed in the WMP.

Figure 5. Location of the Greenville Water Supply, the Tobey Reservoir. USGS Greenville Topographic Quadrangle 1988.

Water use data for the Town of Greenville Water Works for the period of 1999 through 2004 were obtained from the State of New Hampshire. The minimum monthly water use in Greenville during this period was 1,922.7 thousand gallons (June, 2004) and a maximum of 7,322.8 thousand gallons (May, 2001) with an average of 4,515.8 thousand gallons. The daily water use, when converted to cubic feet per second, ranges from a minimum of 0.20 cfs to a maximum of 0.25 cfs with an average of 0.23 cfs.

The Greenville Water Works does not directly withdraw water from the Souhegan River, but does impound tributary flow. Since this system is not directly dependent upon the flow in the Souhegan, the flow protection goal for this IPUOCR is zero.

The remaining PWS systems along the Souhegan River utilize groundwater as their supply source. These include:

- Wilton Water Works
- Milford Water Works
- Pennichuck Water Works, including:
  - Badger Hill – Milford
  - Souhegan Woods – Amherst
  - Amherst Village District – Amherst

Since each of these systems is dependent upon groundwater they are not considered as being dependent upon flow within the Souhegan River. As a result, no specific PISF is proposed for these groundwater Public Water Supplies.

As part of Task 2 performed during this study, UNH analyzed the impact of ground water well withdrawals on the Souhegan River and concluded that the only PWS to induce recharge from the Souhegan River are the Milford Water Works wells (UNH 2005). Although, the Milford Water Works wells induce recharge from the Souhegan River they are not solely dependent upon the river as a source of water. As a result, the ground water wells of the Milford Water Works along with the Wilton and Pennichuck Water Works are not considered to be dependent upon the flow of the Souhegan River for their operation and no specific PISF is proposed for these PWSs. Since the Milford Water Works does induce recharge from the river, its operations will be discussed in the WMP.

IV.) Pollution Abatement

There are currently three permitted wastewater discharges to the Souhegan River or an immediately adjacent tributary to the river. Two of these are municipal wastewater treatment plant (WWTP) discharges (towns of Greenville and Milford), while the third is from a State of New Hampshire fish hatchery which discharges directly into Purgatory Brook, approximately one half mile upstream of its confluence with the Souhegan River. The town of Wilton also has a WWTP, but its treated wastewater is pumped to Milford's collection system and discharged by Milford through their permitted outfall. Table 5 delineates some of the effluent limitations for these wastewater discharges.

Table 5. Details of permitted wastewater discharges in the Souhegan River designated segment.

Facility	Effluent Limitations				
	Design Flow (MGD/cfs)	Maximum Daily BOD (lbs/day)	Maximum Daily TSS (lbs/day)	Whole Effluent Toxicity	
				LC50, % effluent	C-NOEC, % effluent
Greenville WWTP – NPDES #NH0100471	0.233/0.36	97.2	97.2	100	≥14.5
Milford Fish Hatchery – NPDES #NH0110001	2.74/4.24 maximum reported	none	324	none	none
Milford WWTP – NPDES #NH0100919 **Summer (June 1-Oct. 31)** **Winter (Nov 1-May 31)**	2.15/3.33 2.15/3.33	287 448	538 628	100 100	≥28.0 ≥28.0

Source: Individual National Pollution Discharge Elimination System Permits

In addition, there is a suite of other parameters that each permittee must monitor, most of which are for monitoring purposes only and have no specified effluent limitations. Effluent limitations are generally only attached to NPDES permits for those parameters that either reflect required treatment plant operational efficiencies (e.g. pollutant removal efficiencies equivalent to secondary treatment) or which have the potential to cause a violation of water quality standards in the receiving water.

According to Env-Ws 1705.02 of the State's surface water quality regulations (NHDES, 1999), the river flow used to calculate permit limits for aquatic life criteria and human health criteria for non-carcinogens for NPDES permits is "7Q10". The 7Q10 is the average seven day low flow that occurs, on average, once every ten years.

Although 7Q10 is technically a 7-day average flow rather than an instantaneous or daily flow, its use for establishing waste discharge permit limits means that when river flow is at or above 7Q10, the permitted discharges would not, by themselves, cause water quality in the river to be less than applicable water quality criteria. Conversely, when instantaneous river flow is less than 7Q10, water quality criteria could be violated, even though the actual 7-day average flow might be equal to or greater than 7Q10. For this reason, the protected instream flow (PISF) necessary for pollution abatement in the Souhegan is the instantaneous flow that is equal to 7Q10 at and downstream of the points of discharge. These pollution abatement PISFs are provided in Table 6.

Table 6. Protected Instream Flow (PISF) for Pollution Abatement in the Souhegan River.

River section	PISF (7Q10)[1]
MA border to Greenville WWTP	No pollution abatement PISF required
Greenville WWTP to Milford WWTP	2.1 cfs (0.068 cfsm) (estimated 7Q10 at Greenville WWTP
Milford WWTP to the Merrimack River	9.4 cfs (0.067 cfsm) (estimated 7Q10 at Milford WWTP

[1]Estmated from hydrologic evaluation presented in Appendix 3

V.) Hydroelectric Energy Production

Information on hydropower operations in the Souhegan River watershed was obtained through interviews with affected dam owners (ADOs) and examination of records maintained by the NHDES Dam Bureau. Detailed profiles of the hydroelectric facilities and information on the dam specifications can be found in Appendix 1. This information was essential to fully understand the relationship between flow and energy production at each of these facilities. The impoundments behind each of the dams are small and riverine and consequently have minimal storage capacity.

The river corridor contains seven hydroelectric facilities, four of which are actively generating electricity (Table 7).

Table 7. Hydroelectric facilities on the Souhegan River designated segment.

Facility	State Reference Number	Location	Status	Flow Generation Capacity	
				Minimum (cfs/cfsm)	Maximum (cfs/cfsm)
Waterloom[1]	NH00355	New Ipswich	Active	20/0.88	~66/2.91
Otis[1]	NH00041	Greenville	Active	20/0.68	~67/2.27
Chamberlain/Souhegan III[1]	NH02007	Greenville	Active	14/0.47	~140/4.72
Souhegan (Elderly Housing)	NH02006	Greenville	Inactive	Not applicable	Not applicable
Label Arts/Souhegan III	NH00906	Wilton	Inactive	Not applicable	Not applicable
Wilton Hydro Dam	NH00905	Wilton	Inactive	Not applicable	Not applicable
Pine Valley Mill[2]	NH00258	Wilton	Active	14.2/0.14	~235/~5

[1] NHDES hydropower information survey sheets
[2] Personal Communication, Heidi Heller-Blackmer, 2006

Each of the four active generating facilities is permitted as a "run-of-river" station, which means that inflow should equal outflow at all times. One of the stations (Pine Valley) has an associated short bypass reach within which it must maintain a minimum flow of 25 cfs or inflow, which ever is less. None of the other stations have associated bypass reaches or minimum flow requirements, other than the "run-of-river" permit condition.

Hydroelectric energy production is dependent on river flow. Most power is generated at mid-flow ranges since it is seldom economical to install equipment necessary to generate power at very low or very high flows. For the Souhegan hydroelectric facilities, minimum flow requirements range from about 14-20 cfs (0.14-0.88 cfsm), depending on the facility. Consequently, the hydropower PISF for Souhegan River hydroelectric power production ranges from 0.14 – 0.88 cfsm depending on the particular facility (Table 7).

Examination of the 2000-2004 streamflow record for the Souhegan indicates that streamflow is generally insufficient to generate power during the summer and early fall and periodically throughout most of the rest of the year (see Part 2 and Appendix 3). Only during the spring and early summer is streamflow dependably high enough to generate power, and even then it is occasionally too high for optimal production (downstream water levels rise faster than upstream water levels which reduces head). The rest of the year, water generally flows into the reservoirs and over the dams.

There are no AWUs upstream to reduce flows to the Greenville hydroelectric facilities, and withdrawals above the Pine Valley Mill facility are at most 1 cfs (2% of generation at minimum generation capacity and less than ½% at maximum generation) for the Pine Valley Mill facility. It is concluded that the existing system meets the hydroelectric PISF for the Souhegan River to the extent naturally possible.

Some management alternatives to maintain other PISF could change the frequency and magnitude of certain higher flows events and could therefore affect hydroelectric energy production. An example of a management strategy that could influence hydroelectric production is utilization of selected flood control impoundments for storage of water to be used for flow augmentation during low flow conditions. While it is likely that water so stored would be obtained by "flood skimming" when river flows are in excess of hydropower PISF, there still could be some impacts under lower flow conditions. Furthermore, release of these stored waters would be unlikely to be of use for hydroelectric production since flow augmentation needs would be at times when river flow is well below the hydroelectric facility generating minimum flow. If such management strategies become part of the Souhegan Water Management Plan, potential impacts to hydroelectric operations will be addressed at that time.

VI.) Fish and Wildlife Habitat

Study Area

Based on the reconnaissance survey of aquatic habitat the Souhegan River was initially divided into eight reaches with multiple sections within each reach. Representative sections were then selected as sites for the habitat surveys (Figure 6).

Reach 1: (Sections 1 – 15; 11.19 km)
For approximately 11.2 km at the uppermost length of the designated reach, the Souhegan River flows through forested areas and is therefore heavily shaded with large amounts of overhanging vegetation and noticeable woody debris. The substrate consisted primarily of large cobble and bedrock, with small amounts of sand. Geomorphically, the river is dominated by step-pool sequences. Where the Souhegan River runs parallel to Route 31 for 5 km, the banks were sometimes stabilized by riprap and the morphology of short stretches had been altered. Within the river channel, there were discarded pieces of riprap, which alter the substrate and aquatic habitats. Eight percent of the length is impounded by a dam in Greenville. Section numbers 6 (Site 1) and 12 (Site 2) were selected as representative sites of this reach.

Reach 2: (Sections 16 – 22; 3.51 km)
Downstream of the Isaac Frye Highway bridge (sections 17-22), the river flows into an open space, although the banks remain mostly forested. In the vicinity of section 21 and 22, the river flows through the Horseshoe Gorge. In this reach, the habitat types changed including more runs and glides than found upstream. Sections 16 (Site 3) and 18 (Site 4) were selected as representative sites of this reach.

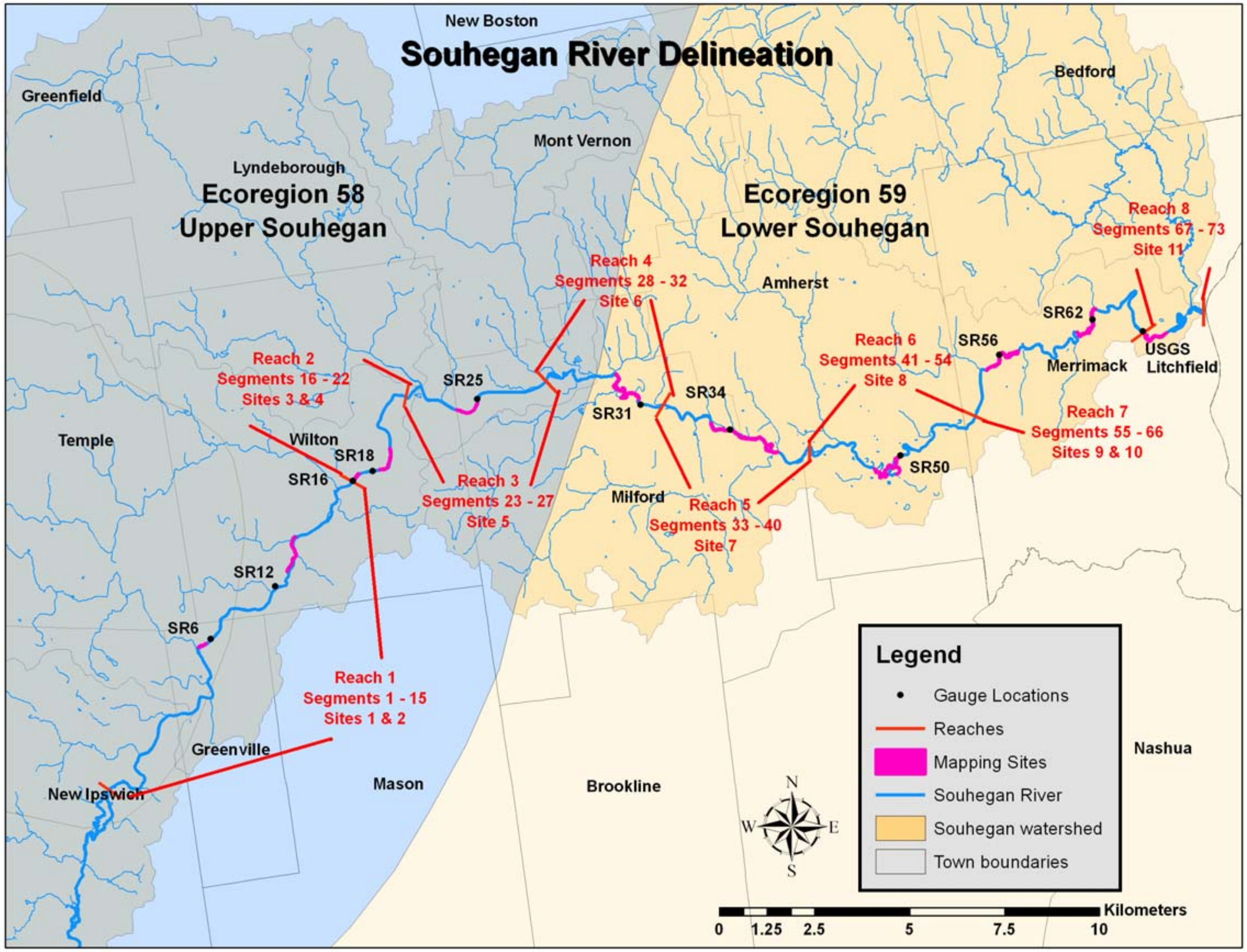


Figure 6. Map of study area. The Souhegan River is shown in blue. Upper and Lower Souhegan Ecoregion zones are shaded. The eight reaches are labeled in red and include their defining segments. Representative mapping sites are shown in pink and labeled sequentially downstream.

Reach 3: (Sections 23 – 27; 4.63 km)
Beginning with section 23, which is impounded, the Souhegan River provides a dramatic contrast to upstream sections in terms of human induced alteration. Directly above the confluence with Stony Brook the Souhegan River enters urbanized areas with heavily stabilized banks. The confluence itself was created and enforced by old mill buildings and bridge crossings. Almost immediately after the confluence, two dams impound the river. Below the dams, the Souhegan River has been realigned as a part of highway construction all the way down to section 27. Twenty-five percent of the 4.6 km length of Reach 3 is impounded.

In this reach the river still had a moderately high gradient yet substrate size reduces to cobble, pebble, and gravel. The habitat type was dominated by glides and riffles. Consequently the boulder and woody debris cover was strongly reduced and banks are stabilized by riprap. Shallow margins (abundant upstream of this reach) were absent. Nevertheless, there was some overhanging vegetation and canopy cover shading. Section 25 (Site 5) was selected as the representative site of this reach.

Reach 4: (Sections 28 – 32; 4.18 km)
The river changes to a low gradient, wide, (20 m) meandering channel. This low gradient continues down to our section 32 and is accompanied by fields covered with remnants of oxbows and former side arms. This approximately 4.18 km long reach has no dams. A number of tributaries join the river in this area.

The substrate changed very dramatically to a high abundance of sand and fines. The riverbanks became steep but covered with overhanging canopy that provides shade and a source of woody debris. The habitat types consisted of runs, pools, glides and riffles. The presence of mussels and dragonflies were first observed in this section. Section 30 (Site 6) was selected as the representative site of this reach.

Reach 5: (Sections 33 – 40; 5.27 km)
Section 33 crosses the town of Milford where the river is impounded by two dams over the length of approximately 1.5 km. This 1.5-km stretch comprises 28% of the total length of this reach. Downstream of the dams (section 34 and 35), the river continues to flow through residential areas and is high gradient. It cuts through bedrock ledge, which is also expected under the impoundments. The river banks in this area have an abundance of riprap as well as overhanging vegetation that does not provide much shading, but indicates the age of the construction. Some woody debris was observed. Downstream of the impoundment the habitat consisted of rapids, riffles, and runs with coarse but mixed substrate embedded in sand. Sections 34 through 37 (Site 7) were selected as the representative sites of this reach.

Reach 6: (Sections 41 – 54; 7.08 km)
Nearly 5 km of this reach is accompanied by a golf course that reduces canopy shading and woody debris. Meandering banks were active. In the areas of bridges was observed heavy bank stabilization with riprap. The substrate was dominated by sand with the presence of submerged underwater vegetation. Hydraulic habitats consisted of runs, pools, and glides accompanied by some low gradient riffles.

Beginning with section 48 the Souhegan River meanders through more forested and residential areas where the abundance of woody debris and canopy shading increases. Also observed were increases in shallow margins and the appearance of a few backwaters. Submerged underwater vegetation was less abundant. The banks were still high and eroded. The hydraulic habitat consisted of runs, pools, and glides accompanied by low gradient riffles associated with woody debris. Sections 47 through 50 (Site 8) were selected as the representative sites of this reach.

Reach 7: (Sections 55 – 66; 9.36 km)
The river turns into a mosaic of long, low gradient stretches interrupted by ledges and large rapids. The river meandered less than it did upstream and the oxbows were less abundant indicating steeper topography of the surrounding landscape. The riverbanks continued to be high and steep, and were covered with mature vegetation. The 9.3 km long reach had no impoundments but riverbanks were associated with residential use.

The dominating substrate continued to be sand with the exception of bedrock in rapids. The river becomes over 30 m wide such that canopy shading does not reach across its width. The hydraulic habitat was dominated by runs, riffles, pools, and glides accompanied by cascades and backwaters. Sections 56, 57 (Site 9) and 61, 62 (Site 10) were selected as representative.

Reach 8: (Sections 67-73; 2.16 km)
Downstream of Wildcat Falls the river flows though the residential and urbanized town of Merrimack. The amount of cascades and ledges significantly increased (there are three cascades in this reach). Therefore the river had more moderate to high gradient character and did not meander. Of the approximately 2.1 km length of this section, an inactive dam impounds 16% of the length. This impoundment creates substantial wetlands.

The hydraulic habitat consisted of runs, riffles, and cascades with an abundance of boulders. Woody debris and shallow margins were present. At the bridge and residential areas the banks were stabilized with riprap. Substrate was a mixture of bedrock, cobble, gravel, sand and fines. Sections 67 through 71 (Site 11), upstream of the Merrimack Village Dam, were selected as the representative sites of this reach.

Segments of the Souhegan River

Based on the physical characteristics of the river observed during our initial survey and described here, distinct geomorphologic differences between the upper (Reaches 1-3) and lower (Reaches 4-8) Souhegan were apparent. Below, the valley began to widen and the gradient of the river became less steep. There was also a noticeable change in the dominant substrate type in the river below this point, from large cobble and boulders with bedrock outcrops, to a dominant substrate type of sand and fine gravel. These sudden changes coincide with the approximate location of the Milford-Souhegan glacial-drift aquifer, an area of unconsolidated glacial-drift deposits consisting primarily of stratified sand and gravel overlain by more recent alluvium (Harte, 1992).

The area of the river where these changes occur also coincides with a zoogeographic Ecoregion boundary (Omernik, 1987). The upper portions of the Souhegan River are within Ecoregion 58, the Northeastern Highlands, and the lower portions of the river extend into Ecoregion 59, the Northeastern Coastal Zone.

The combined effects of changes in gradient, stream order, and surficial geology caused a dramatic change in the dominant substrate type and created a difference in the available habitat types between the upper and lower portions of the river. This led to the belief that there would be differences in the composition of the instream faunal communities between the upper and lower portions of the river.

To account for these expected differences in the fauna, the river was divided into two primary segments: Upper Souhegan River (Reaches 1-3), representing a 3rd order, high gradient stream, and Lower Souhegan River (Reaches 4-8), representing a 4th order, low gradient river. The status of the instream faunal assemblages of these two river segments was investigated, analyzed, and evaluated separately.

Temperature Data

Ten Hobo® temperature probes (Onset computer corporation, Bourne, MA) were installed throughout a 52 km study area starting from the New Ipswich, NH impoundment and ending at the Merrimack River confluence. Temperatures were recorded in the Souhegan River between June 26, 2004 and September 13, 2005. This was a period of 437 days that included portions of two summer seasons. Several temperature probes were lost during the ice break-up and floods during the spring of 2005 and could not be replaced until flows subsided enough to enter the river in late June. This loss limited the number of overlapping days from the two seasons studied. Between 200 and 435 days of temperature data were recovered from each site, which accounts for over 80,000 individual temperature measurements. The location of the temperature probes and reference points are tabulated in Figure 7.

Information regarding the impoundments indicated in Figure 7 may be found in Table 8. The "Description" column qualifies the observed relative size of each impoundment. The named "Reference" column identifies the distance up/downstream from the nearest temperature probe and the "Distance" column gives the downstream distance from the New Ipswich impoundment starting location.

Table 8. Impoundments and reference points of interest along the Souhegan River. Each location includes a brief description of the impoundments relative size or other descriptive information. The reference column refers to the features distance (in meters) up or down-stream from the nearest temperature probe location. The column "distance" is the location of the feature (in meters) downstream from the starting location at the New Ipswich impoundment.

Location	Description	Reference	Distance (m)
Impoundment 1	Large, start of Designated River	New Ipswich impoundment	0
Impoundment 2	very small	963 m downstream Impound1	963
Impoundment 3	Large	9943 m upstream Probe 2	3,788
Monadnock Wells	Bottling Plant	76 m upstream Probe 2	13,481
Impoundment 4	Very Small	31 m upstream Probe 3	17,198
Impoundment 5	Large	137 m upstream Probe 4	18,798
Impoundment 6	Large	2,142 m upstream Probe 5	28,371
Waste Water	Treatment Plant	15 m upstream Probe 5	30,645
Impoundment 7	med/large	576 m upstream Probe 10	51,521

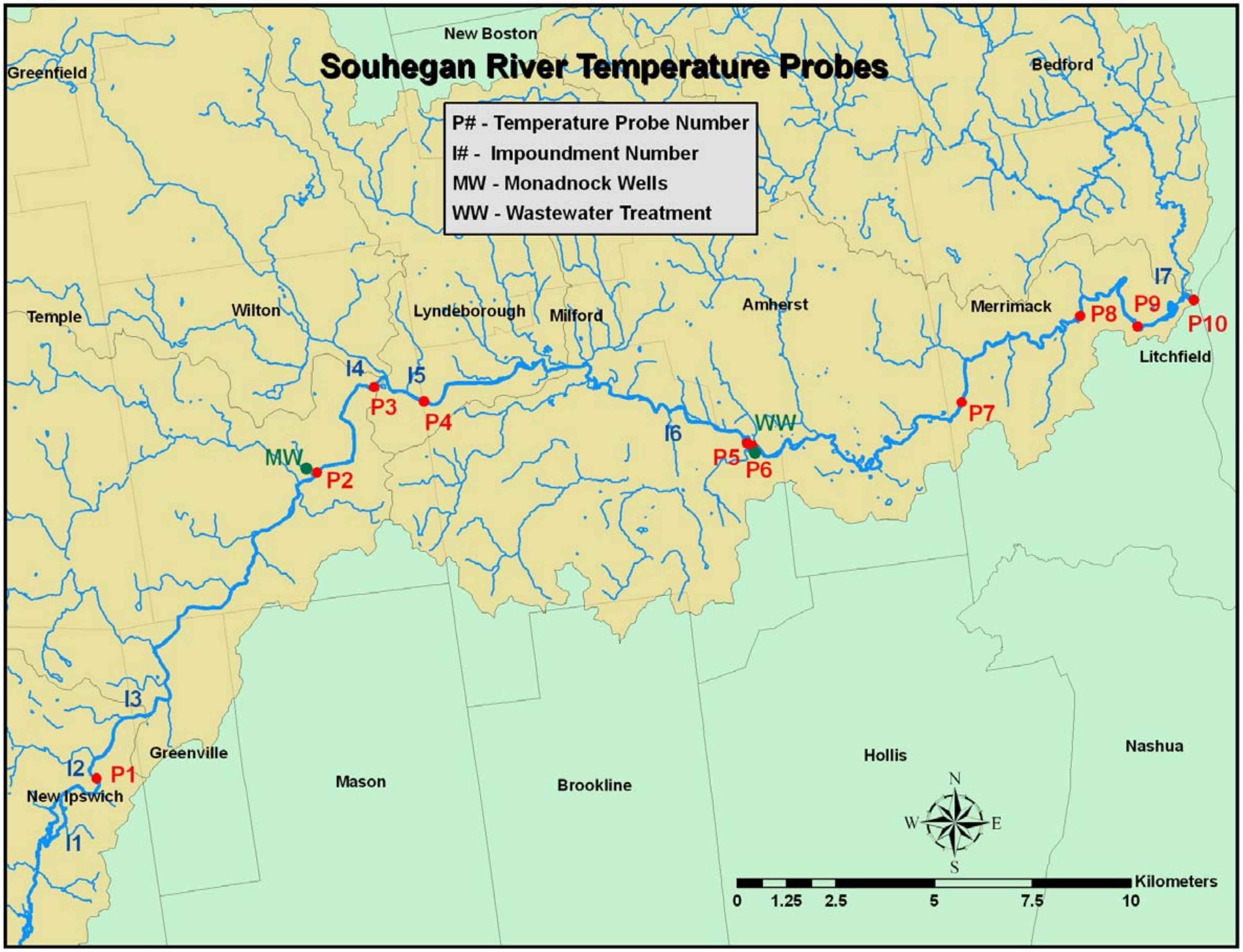


Figure 7. Map showing the location of temperature probes (Red), impoundments (Blue I-numbers), and reference points of interest (Green) on the Souhegan River.

2004 Temperature Results

Because of the loss of several over-wintering probes, the most rigorous comparison of the collected temperature data was to compare only the overlapping days from the two seasons for temperature probes. This restriction therefore limited the comparison to a 64-day period from July 2nd to September 3rd for both the 2004 and 2005 seasons (Table 9).

Table 9. River Water Temperature Data for the 2004 Field Season. "Distance (m)" is the distance in meters between a probe and the closest upstream probe. "Distance from Impoundment (m)" is the probe's downstream distance in meters from the New Ipswich, NH impoundment. "Min Temp" and "Max Temp" are the maximum or minimum hourly temperatures registered during the period of investigation. "Avg. Temp" is the daily average temperature data for the period of record.

Temperature Probe	Distance (m)	Distance from Impoundment (m)	Min Temp. (°C)	Max Temp. (°C)	Avg. Temp. (°C)
1	1,110.6	1,110.6	**18.7**	**24.8**	**21.4**
2	12,446.7	13,557.3	**14.1**	**26.0**	**19.6**
3	3,671.8	17,229.2	**14.9**	**27.5**	**20.5**
4	1,705.8	18,935.0	**17.1**	**27.9**	**20.7**
5	11,578.0	30,513.0	**12.9**	**28.7**	**21.1**
6	147.5	30,660.5	**17.1**	**27.9**	**21.0**
7	9,641.3	40,301.8	**17.5**	**28.3**	**21.0**
8	6,210.7	46,512.5	**17.9**	**28.3**	**20.9**
9	3,618.1	50,130.6	**17.9**	**29.5**	**21.5**
10	1,966.1	52,096.7	**18.3**	**33.2**	**21.7**

2005 Temperature Results

Probe 6 was removed from the longitudinal profile graph for the 2005 season. Probe 6 became buried under sediment in the middle of July, 2005 and after that date it was insulated and recorded a modified temperature that most likely included a strong groundwater component from the adjacent steep bank. It was therefore removed from the longitudinal profile graph for the 2005 season.

Figure 8 is a longitudinal temperature profile for the period between July 2, 2004 and September 3, 2004.

Table 10. River Water Temperature Data for the 2005 Field Season.

Temperature Probe	Distance (m)	Distance from Impoundment (m)	Min Temp. (°C)	Max Temp. (°C)	Avg. Temp. (°C)
1	1,110.6	1,110.6	**19.1**	**26.8**	**23.2**
2	12,446.7	13,557.3	**14.4**	**27.5**	**20.9**
3	3,671.8	17,229.2	**16.0**	**28.7**	**21.4**
4	1,705.8	18,935.0	**15.9**	**28.3**	**21.9**
5	11,578.0	30,513.0	**16.4**	**28.7**	**22.5**
6	147.5	30,660.5			
7	9,641.3	40,301.8	**16.8**	**25.6**	**21.7**
8	6,210.7	46,512.5	**16.7**	**27.1**	**22.3**
9	3,618.1	50,130.6	**16.7**	**26.3**	**22.5**
10	19,66.1	52,096.7	**12.9**	**29.1**	**22.7**

In 2004, average river water temperatures during this study period tended to cool downstream, after leaving the New Ipswich impoundment, for approximately 14 km until the area below the Isaac Frye Highway (intersection of Route 31 and 101) and the small impoundment located near Island Street (Wilton). Downstream of Wilton, temperatures remained fairly constant or rose slightly until the area between probes 8 and 9. Downstream of Turkey Hill Road (Merrimack) temperatures began to increase more noticeably at the probes located in Wildcat Falls and at the Merrimack River confluence.

Average temperatures during the 2005 study period also tended to cool, after leaving the New Ipswich impoundment, downstream for approximately 14 km until the area between the Monadnock bottling plant (intersection of Route 31 and 101) and the small impoundment located near Island Street (Wilton). Downstream of Wilton temperatures rose slightly until probe 5 or 6 at the Milford wastewater treatment plant. Arrowed lines (Figure 9), indicating likely temperature trends, were added to the graph between probes 5 and 7 because of the loss of temperature probe 6. Average temperatures decreased slightly during the study period between probes 5 and 7 before increasing gradually to the Merrimack River confluence (Figure 9).

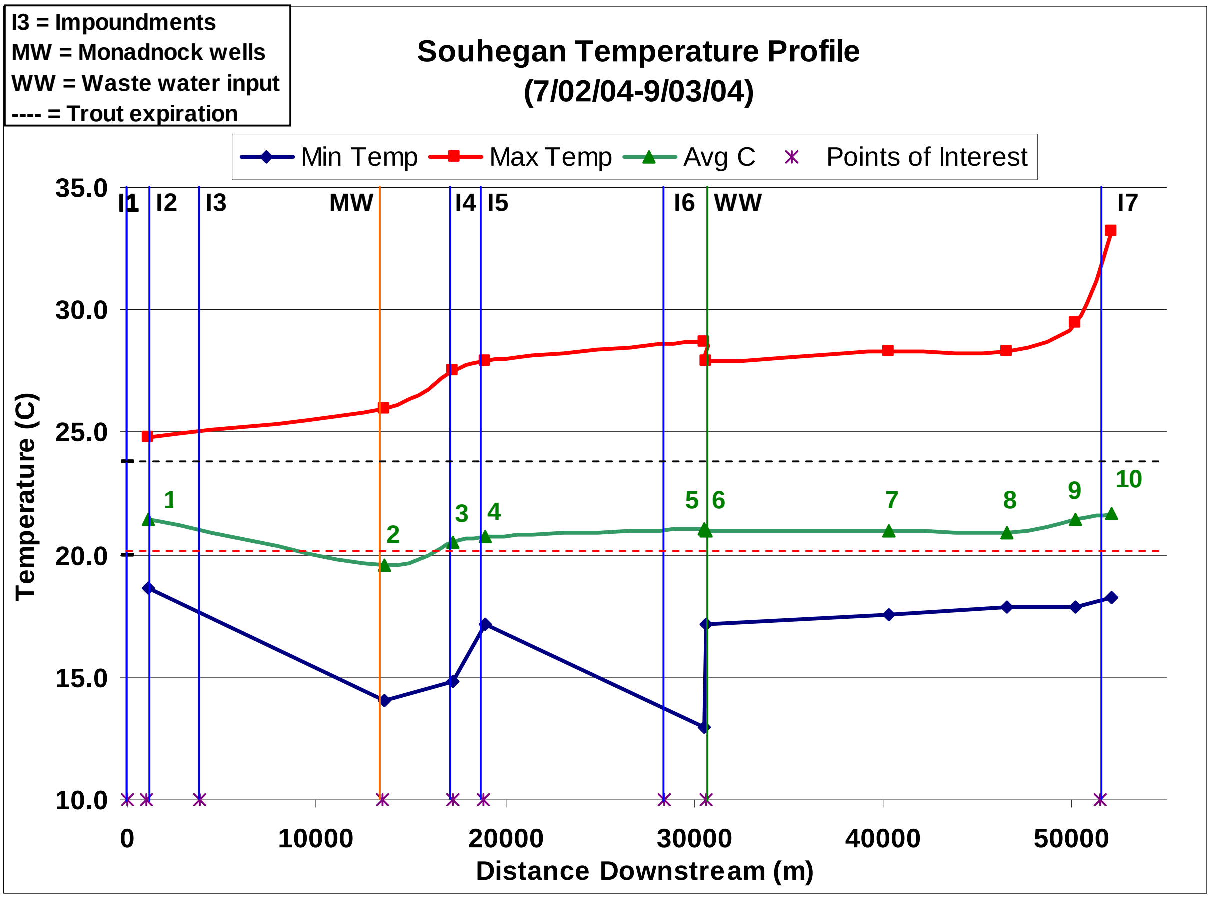


Figure 8. Souhegan River longitudinal temperature profile for the period of days common to the 2005 temperature data. Temperature probe locations (shown as square, triangle, and diamond symbols in Figure 10) are plotted by their downstream positions in relation to the New Ipswich, NH impoundment and are labeled with green numbers. Maximum hourly temperatures are shown in red, minimum hourly temperatures in blue and daily averages in green. Vertical lines indicate the reference points (see Table 8). A red dashed line at 20 ºC represents the upper optimal temperature range for Eastern brook trout (EBT). The black dashed line at 23.8 ºC represents the maximum tolerable temperature for EBT if fast moving/turbulent water and high oxygen levels are present.

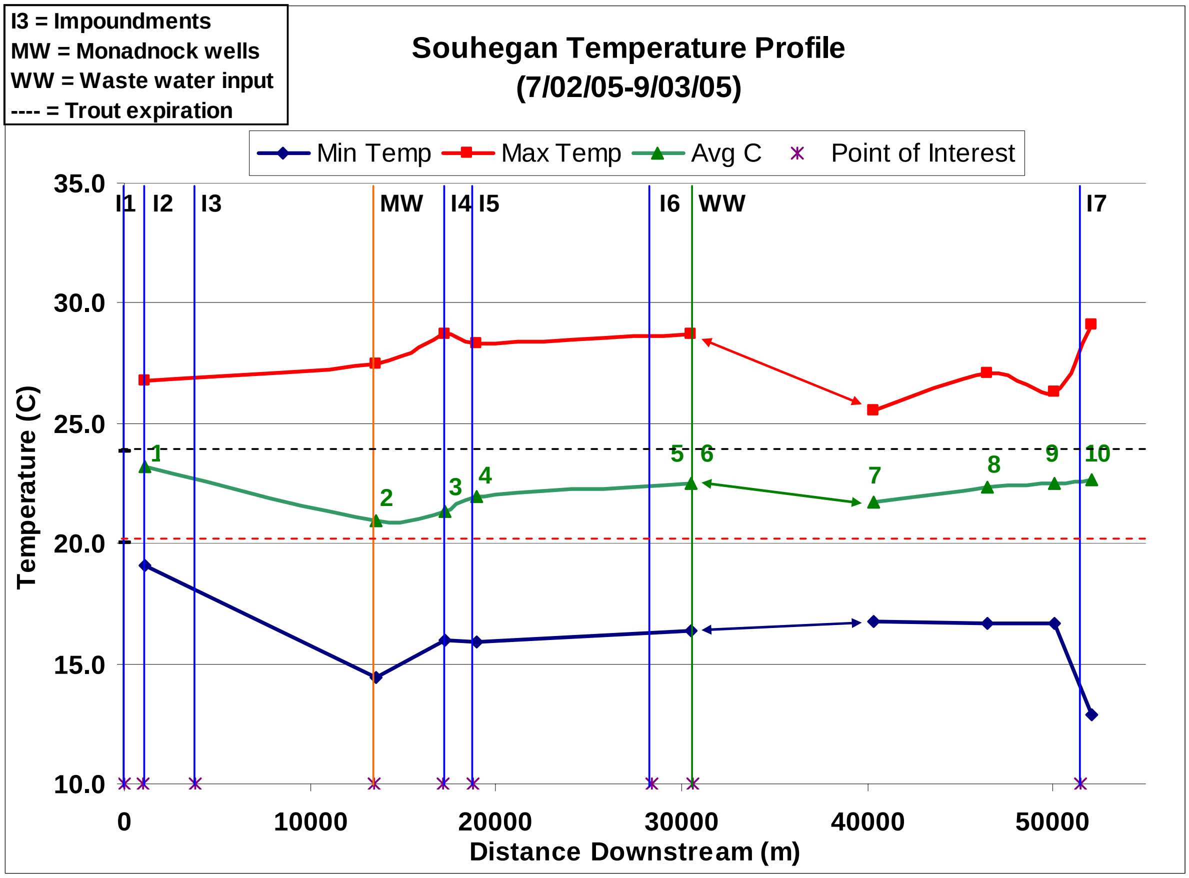


Figure 9. Souhegan River longitudinal profile for the period of days common to the 2004 temperature data. Minimum (blue) and maximum (red) temperatures for the period of record. Horizontal green line is the average daily temperature at each probe location plotted by distance from the New Ipswich impoundment. Vertical lines refer to reference points along the river: impoundments in blue, the Isaac Frye Highway in orange, and the Milford wastewater treatment plant outfall in green.

There are numerous flood protection reservoirs located in the tributary headwaters of the Souhegan River watershed. Observation of elevated water temperatures in the Upper Souhegan leads to the suspicion that these shallow impoundments contribute to high temperatures through their absorption of solar radiation. Therefore, on a hot day of August 8, 2005 an investigation of water temperatures within impoundments and their outflows at multiple locations was conducted. Temperatures were measured using a non-contact (infrared) thermometer at the water's surface both upstream and downstream of each impoundment. Water temperatures of impoundment outflows ranged between 21.1°C below the New Wilton Reservoir and 32.7°C at the northern outflow of Senator Toby Reservoir (Site 12 B) in Temple, New Hampshire. Temperature measurements and site locations are given in Table 11.

Table 11. Locations and water temperature measurements of impoundments within the Upper Souhegan River watershed.

Date	Time	Water body name/Dam Site	Pond Temp. (°C)	Outflow Temp. (°C)
8/8/2005	10:00	New Wilton Reservoir	28.6	21.1
8/8/2005	10:30	Unknown	21.4	22.5
8/8/2005	11:00	Site 15 Dam (Batchelder Pond)	26.6	23.3
8/8/2005	11:30	Site 12A North	26.6	28.3
8/8/2005	11:45	Site 12 A South	32.7	32.7
8/8/2005	13:30	Water Loom Pond	29.7	26.6
8/8/2005	14:30	Site 19 Dam	27.2	29.4

Temperature Discussion

Average temperatures in the two summer seasons studied follow similar trends for the 64-day period. Two exceptions were the slight dip in average temperatures at Probe 7 located near Seaverns Bridge in Merrimack and the increase in the 2005 average temperatures by 2 degrees Celsius at each probe.

Temperatures in the upper watershed are dramatically influenced by several impoundments on the tributaries. During summer, even the lowest Souhegan River water temperatures are high in regional comparison. It takes at least 14 km for the river waters to cool and mix with groundwater. Average temperatures begin to increase near the Isaac Frye Highway and below each of the two downstream impoundments before leveling off and remaining constant or slightly rising over the next 30 km of river. The water temperature of the Merrimack River may influence the probe located at the Souhegan/Merrimack River confluence during certain flows.

Daily average temperatures remained above the maximum optimal temperature range for brook trout in both periods of record with the exception of Probe 2 in the 2004 season. Daily average temperatures approached the maximum survival temperature for brook trout in fast-flowing, oxygenated waters during the two periods of study. Maximum daily temperatures during both periods of study far exceeded the water temperature requirements for brook trout. These temperature thresholds could also apply to other cold water fish species like slimy sculpin, Atlantic salmon, longnose sucker and transitional species like longnose and blacknose dace.

Bio-Periods

Timing of flows is one of the components of the Natural Flow Paradigm. The flow regime and the flow requirements of fauna within a stream vary through the year. When identifying protected flows in a river, it is necessary to consider the flow and habitat fluctuations to which the aquatic species have adapted. To achieve this, the year was partitioned into biological periods (bio-periods) when migratory species and specific life stages of resident fauna are particularly dependent upon appropriate flows. These bio- periods reflect the special or critical times that the availability of habitat required by a particular fauna or life stage may be dependent upon flow conditions.

The timing and duration of these bio-periods was determined using a literature-based analysis of the life histories and biological needs of the resident target species identified in the Target Fish Community section (TFC) (Section IX), and the fluvial dependent, diadromous pulse species that have the potential to occur within the Souhegan River. The timing of these seasonal bio-periods was then compared to the flow conditions of the Souhegan River using a hydrograph of mean daily flows reported for the USGS Souhegan River gauge at Merrimack, New Hampshire (based on 71 years of record) (Figure 10).

Spring/fall spawning and low flow summer survival/rearing and growth conditions were considered the primary biological periods of importance based on professional experience in fish ecology and instream flow studies. Over-winter survival and salmonid egg development and the spring flood/storage periods, were evaluated solely by the simulated hydrograph since data for the targeted fauna were extremely sparse for these two periods.

The spawning periods of the top five target resident species in the TFC were selected and the two selected extirpated anadromous species (Atlantic salmon and American shad) from literature sources (Armstrong et al. 2003; Hartel et al., 2002; Ross and Reed, 1978; Scarola, 1987; Smith, 1985; Stier and Crance, 1985; Whitworth, 1996).

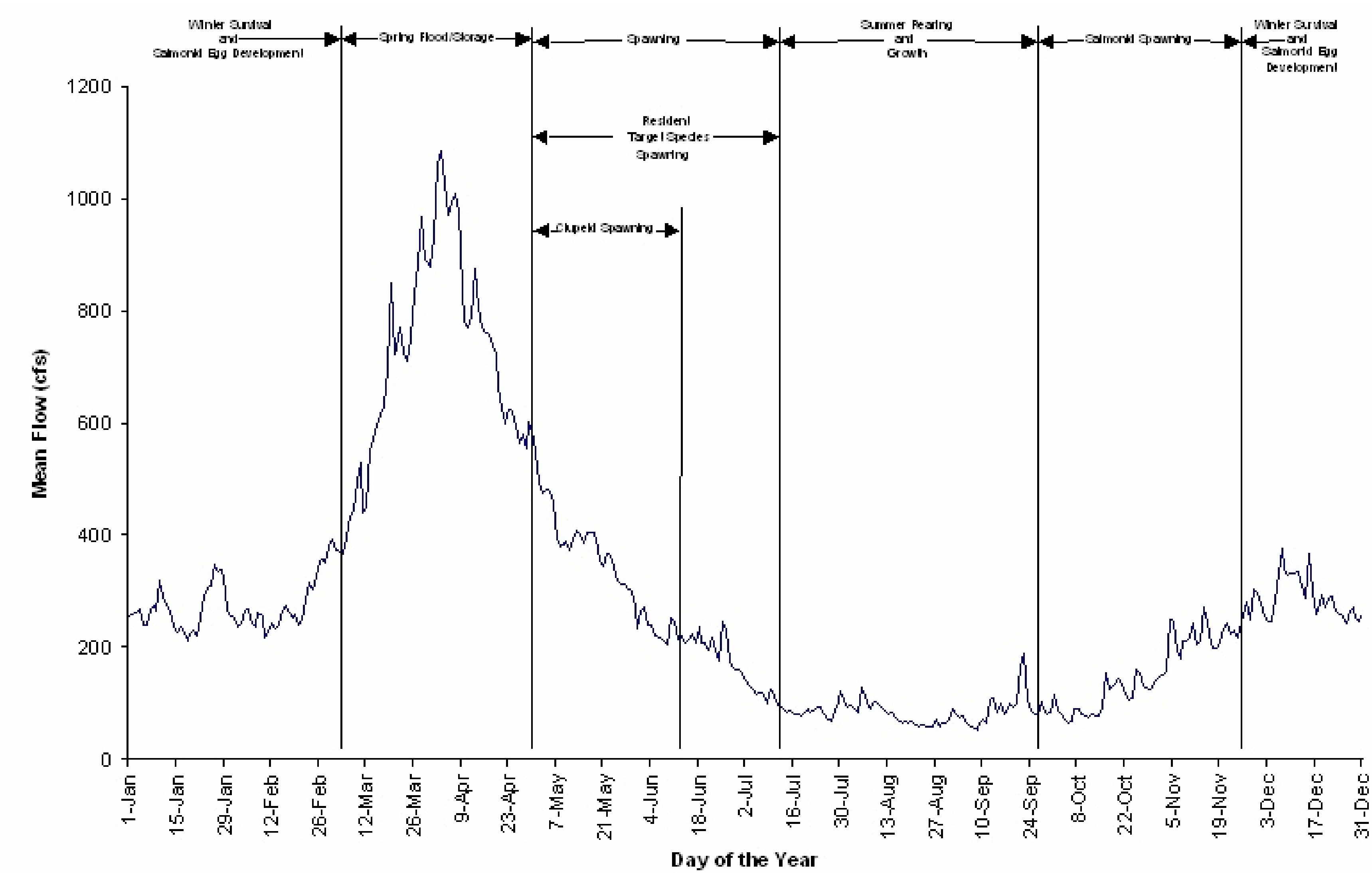


Figure 10. Bio-periods identified for the Souhegan River displayed over the Souhegan River daily mean hydrograph based on 71 years of record.

Wetland/Riparian Wildlife Habitat

Many species of wildlife were observed to use the deep and shallow oxbow marshes, backwaters, floodplains and riparian edges along the Souhegan River. Table 12 lists the species observed during the field reconnaissance and transect surveys. Although the list is not a complete list of species potentially using the river, it includes some of the more common species and those easily detectable by song or track. Wildlife species that have an aquatic life phase for which water levels are critical, such as frog eggs and larvae, and those that forage principally on flow-dependent prey during a critical life phase (brood rearing, migration) such as swallows, kingfishers and bats, are more flow dependent than mobile terrestrial species that forage opportunistically in the wetlands (e.g. deer, chipmunks). Flows that deviate substantially from the Natural Flow Paradigm during the growing season (April through October) will have the most significant effects on flow-dependent wildlife, as the adaptive behaviors and food chains may be upset. For example, higher flows in early summer may destroy turtle or waterfowl nests, while lower flood levels in spring may fail to fill oxbow marshes where amphibians breed. Protective flows for many wildlife species using wetlands and floodplains are represented by protective flows determined for the Wood Turtle, Fowler's Toad, and oxbow marshes, as described in Section VIII. Water temperature changes that alter the timing of macroinvertebrate life cycles (for example, emergence of insects important to breeding or migrating songbirds) could also adversely affect wildlife. Protective flows for aquatic/emerging insects are represented by those identified for odonates (see Section IX).

Table 12. Wildlife Species Observed Along the Souhegan River during 2005 Site Reconnaissance.

Common Name	Scientific Name	Habitat Observed in
Reptiles and Amphibians		
Green Frog	*Rana clamitans melanota*	Back swamps
Spring Peeper	*Hyla crucifer*	Back swamps, pools
Gray Tree Frog	*Hyla versicolor*	Floodplain pools
Bull Frog	*Rana catesbeiana*	Channel
American Toad	*Bufo a. americanus*	Oxbow, backwater, land
Eastern Painted Turtle	*Chrysemys p. picta*	Channel, oxbow
Wood Turtle	*Clemmys insculpta*	Channel
Mammals		
Eastern Chipmunk	*Tamias striatus*	Riparian edge
Red Squirrel	*Tamiasciurus hudsonicus*	Riparian edge
Mink	*Mustela vison.*	Riverbank
Muskrat	*Ondatra zibethicus*	Channel, oxbow
Raccoon	*Procyon lotor*	Oxbow, bank
Beaver	*Castor Canadensis*	Oxbow, bank
White-tailed Deer	*Odocoileus virginianus*	Oxbow, floodplain

Table 12 (cont.). Wildlife Species Observed Along the Souhegan River during 2005 Site Reconnaissance.

Birds		
Common Name	**Scientific Name**	**Habitat Observed in**
Great Blue Heron	*Ardea herodias*	Oxbow, Bank
Canada Goose	*Branta Canadensis*	Channel
Mallard	*Anas platyrhynchos*	Channel
Green-winged Teal	*Anas crecca*	Channel
Common Merganser	*Mergus merganser*	Channel
Double-crested Cormorant	*Phalacrocorax auritus*	Channel
Osprey	*Pandion haliaetus*	Channel, floodplain
Ruffed Grouse	*Bonasa umbellus*	Floodplain field
Spotted Sandpiper	*Actitis macularia*	Gravel bars
Mourning Dove	*Zenaida macroura*	Floodplain
Black-billed Cuckoo	*Coccyzus erythropthalmus*	Floodplain forest
Chimney Swift	*Chaetura pelagica*	Over channel
Belted Kingfisher	*Ceryle alcyon*	Channel
Hairy Woodpecker	*Picoides villosus*	Floodplain forest
Eastern Phoebe	*Sayornis phoebe*	Riparian edge
Eastern Wood Pewee	*Contopus virens*	Floodplain Forest
Great Crested Flycatcher	*Myiarchus crinitus*	Floodplain
Eastern Kingbird	*Tyrannus tyrannus*	Riparian edge
Red-eyed Vireo	*Vireo olivaceus*	Floodplain
Blue Jay	*Cyanocitta cristata*	Floodplain forest
American Crow	*Corvus brachyrhynchos*	Floodplain
Tree Swallow	*Tachycineta bicolor*	Channel
Bank Swallow	*Riparia riparia*	Channel, bank
Black-capped Chickadee	*Poecile atricapilla*	Wooded eastern edge
White-breasted Nuthatch	*Sitta carolinensis*	Floodplain Forest
American Robin	*Turdus migratorius*	Floodplain
Gray Catbird	*Dumetella carolinensis*	Riparian edge
Cedar Waxwing	*Bombycilla cedrorum*	Channel, Riparian edge
Common Yellowthroat	*Geothlypis trichas*	Riparian edge
Northern Waterthrush	*Seiurus noveboracensis*	Channel debris

Table 12 (cont.). Wildlife Species Observed Along the Souhegan River during 2005 Site Reconnaissance.

Birds		
Common Name	**Scientific Name**	**Habitat Observed in**
Black and White Warbler	*Mniotilta varia*	Floodplain
Yellow-rumped Warbler	*Dendroica coronata*	Riparian edge
Chestnut-sided Warbler	*Dendroica pensylvanica*	Floodplain
Prairie Warbler	*Dendroica discolor*	Floodplain
Scarlet Tanager	*Piranga olivacea*	Floodplain
Savannah Sparrow	*Passerculus sandwichensis*	Floodplain field
Song Sparrow	*Melospiza melodia*	Floodplain field
Northern Cardinal	*Cardinalis cardinalis*	Floodplain
Bobolink	*Dolichonyx oryzivorous*	Floodplain field
Red-winged Blackbird	*Agelaius phoeniceus*	Oxbow, back swamp
Common Grackle	*Quiscalus quiscula*	Channel
Baltimore Oriole	*Icterus galbula*	Floodplain
House Finch	*Carpodacus mexicanus*	Floodplain
American Goldfinch	*Carduelis tristis*	Floodplain

VII.) Aquatic and fish life maintenance and enhancement

(See Sections VI and IX).

VIII.) RTE: Fish, wildlife, vegetation, and natural/ecological communities

Flow dependent rare, threatened and endangered wildlife, plants and natural communities are listed in Table 13 along with their flow requirements. Flow dependency varies seasonally with critical bioperiods during spring for floodplain-adapted species and communities; summer low flows for breeding and nesting wildlife; and winter for hibernating turtles (Figure 11). The PISF for these resources are described below.

A. Rare, Threatened, and Endangered Wildlife

Wood Turtle (*Clemmys insculpta*)

<u>Location and Description</u>
The Wood Turtle is a riparian species of special concern in New Hampshire, found in and near low gradient, slow moving rivers and streams with sand/gravel substrates and densely vegetated shrub and vine borders (Carroll, 1993), as may be found on the lower Souhegan River from Amherst to Merrimack.

Table 13. Natural Communities, Wildlife Habitats and RTE Wildlife and Plants

IPUOCR	Status	General Location	Sensitive Bioperiod(s)	General Flow Requirements.	PISF (at Merrimack Gauge)
Wood Turtle *Clemmys insculpta*	Special Concern	Lower Souhegan	June through Sept.	No flooding during nesting in mid to high floodplain	< 1,000 cfs (5.8 cfsm)
			Nov. through March	No exposure during in-channel hibernation	Dec-March flows above mean Oct-Nov flows (107 – 225 cfs)
Fowler's Toad *Bufo Fowleri*	Special Concern	Lower Souhegan	April through May	High spring flows to fill backwaters/oxbows	>600 cfs (3.5 cfsm) (based on transect obs.)
			Late May through mid-Aug.	Sufficient inundation of eggs/tadpoles in backwaters	>30 cfs (0.18 cfsm) (based on transect And MESOHabsim)
Osprey *Pandion haliaetus*	State-Threatened	Lower Souhegan	Spring through Fall	Sufficient flows to protect prey (fish) in channel	(see GRAF Fish recommended flows)
Common Loon *Gavia immer*	State-Threatened	Lower Souhegan	Spring through Fall	Sufficient flows to protect prey (fish) in channel	(see GRAF Fish recommended flows)
Wild Garlic *Allium canadense*	State-Threatened	Lower Souhegan	Spring	Occasional scouring by high spring floods	>5,000 cfs (29.2 cfsm) every 10 years (10-yr flood)
Wild Senna *Cassia hebecarpa*	State Endangered	Lower Souhegan	Spring	Occasional scouring by high spring floods	>5,000 cfs (29.2 cfsm) every 10 years (10-yr flood)
High-Energy Riverbank	S3/S4	Upper Souhegan	Spring/Winter	Flood and ice scour of bankfull channel	>500 cfs (2.9 cfsm)
Silver Maple Floodplain Forest	S2	Lower Souhegan	Spring	1-3 year flooding (< 2 yr return flood)	>2,000 cfs (11.7 cfsm) every 1-3 years
Sycamore Floodplain Forest	S1	Upper Souhegan	Spring	1-3 year flooding (>two-year return flood)	>3,000 cfs (17.5 cfsm) every 1-3 years
Oxbow/Backwater Marsh	S3	Lower Souhegan	Spring	Filling of backwaters/oxbows	>600 cfs (3.5 cfsm) in spring
			Summer	Transect obs. of water levels	>30 cfs (0.18 cfsm) part of summer

Spring through fall the Wood Turtle moves frequently between land and water. This movement can be hampered by high, steep riverbanks. The steep 5-9 ft banks typical of the low gradient parts of the Souhegan River indicate a possible entrenchment tendency, so this is not ideal Wood Turtle habitat in many locations. Nevertheless, Wood Turtles have been observed at several locations on the lower Souhegan River.

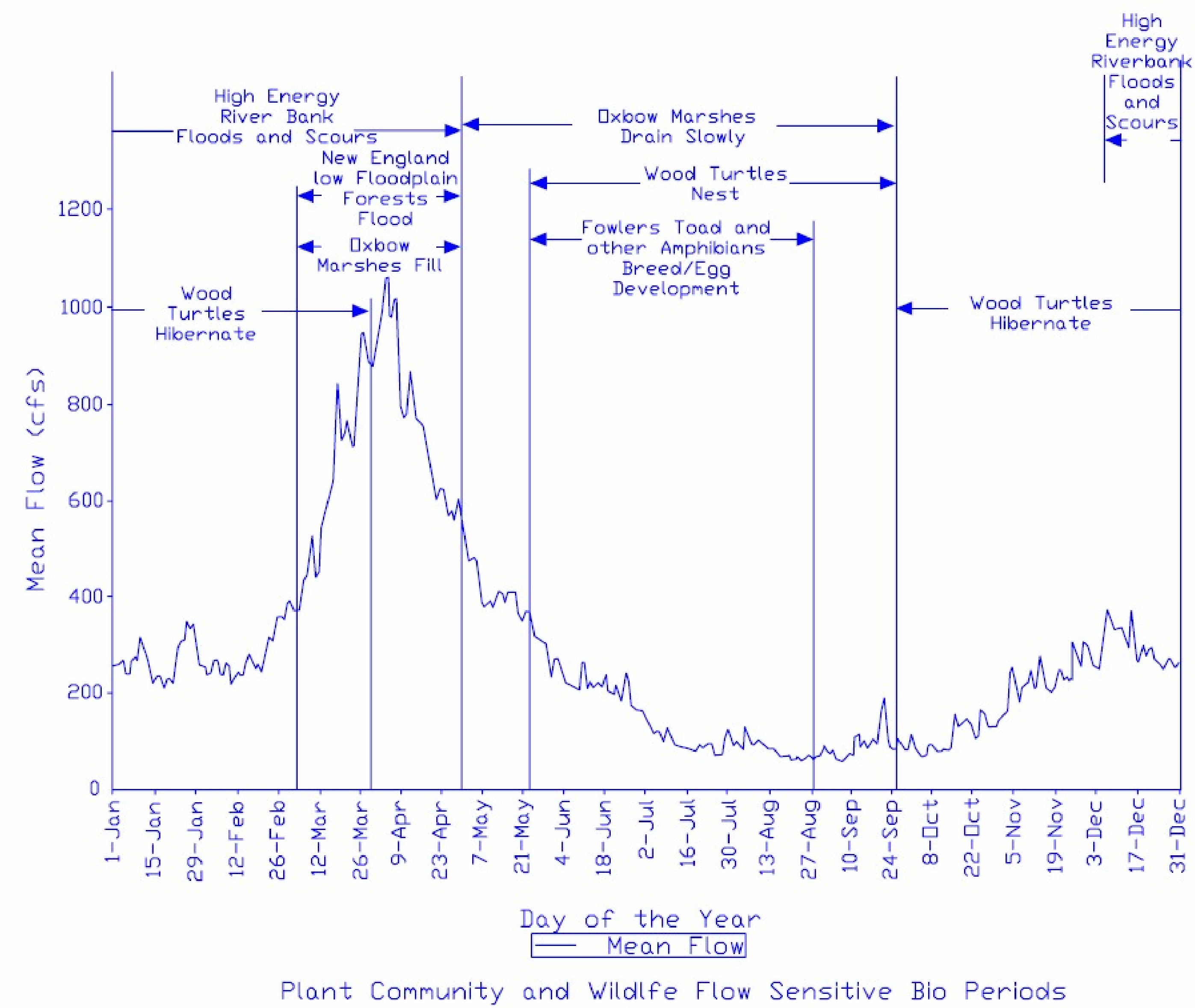


Figure 11. Flow Sensitive Bioperiods for RTE Wildlife and Natural Communities

The Wood Turtle excavates a nest in sandy banks or adjacent farm fields, laying 4 – 18 eggs in late May to early July. Flooding of nests by high summer flows before the hatchlings leave (in August to early October) can cause direct mortality (NHF&G 2005). Sometime in October or November, depending on weather, the Wood Turtle returns to the water until spring and may enter hibernation. Some Wood Turtles return to the same hibernacula each year (Ernst, et al 1994, NHF&G 2005). The Wood Turtle typically hibernates under water in undercut banks or burrows, beaver lodges, pools on the river bottom, or under submerged debris piles/logs in the river channel. In Massachusetts, they have been observed hibernating in 0.3 to 0.6 meters of water in flowing streams (Ernst, et al 1994). Some turtles continue to be alert and mobile in the winter under river ice and show little sign of hibernating (Hanson, ND). Many turtle activities appear to be temperature dependent, and therefore dates vary from year to year. Hibernating turtles are susceptible to injury or death if exposed to ice or below freezing air temperatures after settling into hibernation sites in autumn. However, non-hibernating Wood Turtles may relocate as needed if water levels decline in winter.

<u>Evaluation Method</u>
Flow requirements for Wood Turtles were determined using the Floodplain Transect Method in the low gradient portion of the Souhegan River. This included a topographic survey of the channel and adjacent banks and floodplain; cover type mapping in the selected segment; and development of cross-sections with plant community boundaries and water levels at various flows. Transects R6 S51 T-1 and R7 S59-60 T-1 are representative of low gradient portions of the Souhegan River (Appendix 16).

<u>Flow Requirements</u>
Water level changes assumed to be adverse to wood turtles are:

- Low winter flows (Dec – Feb) that drop below the November levels, potentially exposing hibernating turtles in stream banks or pools;
- Release of water in June, July, August or September that floods turtle nests in the floodplain; and
- Flow changes that accelerate channel incision.

The median daily streamflow curve for the Souhegan River based on 70 years of data (over a 94-year time period) indicates that water levels are typically lowest in August and September, gradually rising in October and November and remaining fairly stable until rising in March through April. Deviations from the norm have occurred. A review of monthly mean streamflow over this same 70-year data set indicates that mean December flows were at least 10% lower than mean November flows in 15 of 70 years (21%). Mean December flows were at least 30% lower than mean November flows in eight of 70 years (11%), and in four of these years there was a further drop of at least 10% monthly streamflow in January to well-below the monthly mean. In almost all cases, the mean winter flows were still high enough to keep channel pools and deeper bank hibernacula submerged. If the WMP considers a management strategy that would regularly reduce winter flows below the October/November mean flows of any given year (average of 0.97 cfsm), then winter minimum flow needs for this species will be further evaluated.

Based on observed flooding on April 5, 2005 at Transects in Reaches 7 and 8, flows of 2,000 cfs at the Merrimack gage (11.7 cfsm) flood the riverbanks and lower floodplain. Flows of 666 cfs (3.89 cfsm) in early June are well within the channel and unlikely to flood most turtle nests. Flows above 1,000 cfs (5.85 cfsm) in June, July, August, September, or early October have the potential to flood the lower sand banks and levees in which some turtles may nest. Since the mean daily streamflow in the Souhegan River for 71 years of record is less than 300 cfs during this period, only an infrequent storm event, dam failure, or planned release would likely cause such a flow. Controllable flows above 1,000 cfs (5.85 cfsm) should be avoided during June through October.

Fowlers Toad (*Bufo fowleri*)

Location and Description

Historical records of the rare Fowler's Toad include several locations on the lower Souhegan River, and although this species was not observed during the field investigation, suitable habitat is present. The Fowler's Toad prefers sandy outwash soils. As with the common American Toad (*Bufo americanus*) which was observed, Fowler's Toads are water dependent for breeding, eggs, and larval stage, and would likely use the same shallow, still margins of the Souhegan River in which American Toad tadpoles were observed, although breeding in other water bodies is also possible. Reduction in flows that expose the shallow river margins, backwaters, and oxbows during larval development may strand and eliminate cohorts of toad tadpoles. Fowlers Toad breeds from late May to August, about one month later than American Toads, with tadpoles transforming 6 to 8 weeks later (generally midsummer) (Degraaf and Yamasaki 2001).

Evaluation Method

Flow requirements for the Fowlers Toad were determined using the Floodplain Transect Method along the lower Souhegan River. This included a topographic survey of the channel, adjacent banks, backwaters, oxbows, and floodplain; cover type mapping in the selected segment; and development of cross-sections with plant community boundaries and water levels at various flows. Sites 8 and 10 have backwaters and oxbow marshes, which are represented on Floodplain Transects R6 S49-50 T-2 and R7 S61 T-2 (Appendix 16). These sites supported American toad larvae and were assumed to be representative habitat for Fowler's toad. In addition, the MesoHABSIM model figures were consulted to identify which oxbows and backwaters were drained at selected target flows.

Flow Requirements

Critical water levels for Fowler's and American Toads are assumed to include:

- Standing water until mid-August at least 3 inches deep (0.25 feet) in backwaters and oxbow marshes (that were flooded during May and June).

The required flow will be different for each potential breeding area, since the oxbow and backwater connections to the river vary in elevation. Based on the observed water levels at cross-sections and MesoHABSIM data from Transects at R6 S50 and R7 S61, flows of approximately 3.5 cfsm (between 400 and 600 cfs at the Merrimack Gauge) in spring would fill the small backwaters located on these transects that do or could serve as breeding pools. Flows above 30 cfs, or 0.18 cfsm (based on the MesoHABSIM site maps) through August would maintain standing water in at least some of the oxbow marshes that serve as breeding areas.

Pied-Billed Grebe (*Podolymbus podiceps*)

The State-endangered Pied-Billed Grebe was reported from the Amherst Country Club. This species was not observed during the field visit June 28-30, 2004. Preferred habitat is densely vegetated emergent and deep marsh interspersed with open water that is more than 12 acres in size ((Degraaf and Yamasaki 2000; Banner 1998). Specific needs of the Pied-billed Grebe are that standing water must always be present, so to the extent that such a marsh is dependent on river flow, this marsh bird species would be flow dependent. A preliminary inspection of aerial photos and NWI maps of the Souhegan River floodplain indicates that there are no marshes of this size within 500 feet of the Souhegan River. It is unlikely therefore, that flow-dependent breeding habitat for the Pied-billed Grebe is present in the project area.

Osprey (*Pandion haliaetus*)

The Osprey is a State-threatened bird-of-prey observed foraging over the fish hatchery in Milford, over the river during the field survey, and reported from the Amherst Country Club. The closest known New Hampshire osprey nest to the hatchery is at Lake Massabesic in Auburn/Manchester (NH Fish & Game website), which is well beyond the approximate 7 mile maximum foraging range reported for ospreys (Vana-Miller 1987). Ospreys observed along the Souhegan River in summer could be transient individuals. Ospreys consume primarily fish from clear, unobstructed water bodies. They dive up to 3 feet into the water, and are most likely to feed in the pools and reservoirs, although they may take fish with their feet in more shallow areas. Only changes in flow that eliminate pools, reduce fish abundance, increase turbidity, or increase aquatic plant cover are likely to affect Ospreys. Flows that are protective of a healthy fish community will be protective of this species.

Common Loon (*Gavia immer*)

The Common Loon was reported by the Amherst Country Club, although it is unlikely to be a breeding resident along the river. This State–threatened bird could use the Souhegan River seasonally to forage for fish, its primary food. The Souhegan River is not likely to be a primary habitat for the Common Loon, but foraging opportunities for loons would be indirectly affected by changes in flow as for the Osprey. Flows that are protective of a healthy fish community will be protective of this species.

B. Rare, Threatened, and Endangered Plants

Long's Bitter Cress (*Cardamine longii* Fern.)

Long's Bitter Cress is an obligate aquatic plant. If present in the project area, it is likely to be flow dependent. Consultation with Dan Sperduto of the Natural Heritage Inventory indicates that this is typically an estuarine species, and the record for Greenville may in fact be an error. It is more likely that the community that the record is for was Greenland. Nor further evaluation for this species is proposed.

Wild Garlic (*Allium canadense*)

Wild Garlic (*Allium canadense*) is a facultative upland plant on the State-Threatened List in NH with a State Rank of 1 (imperiled because of rarity (generally less than six occurrences) or other factors demonstrably make it very vulnerable to extinction). An historical record exists for the Town of Merrimack, but the location is unknown and may not be within the Souhegan watershed. In Maine, the habitat for this species is described as usually found in rich, wooded bottomland hardwoods, in alluvial soils near streams (Maine Department of Conservation, Natural Heritage Program Biological and Conservation Database 2004). Magee and Ahles (1999) describe its habitat in New England as low wet woods and thickets, and rich woods. Though little information was available about the habitat of wild garlic in Merrimack, its classification as a facultative upland plant (USFWS, 1988) and habitat information suggest it occurs on the upper terraces of streams and rivers. These terraces are typically affected by infrequent flooding events (often 10-year storms or greater), and so may be somewhat dependent on periodic scouring for survival. It was therefore considered flow-dependent on higher flows. If water management alternatives considered in the Water Management Plan affect high flows, then potential impacts to this IPUOCR will be addressed in the WMP.

Wild Senna (*Cassia hebecarpa*)

There are historical records of the State Endangered Wild Senna in three of the towns along the Souhegan River as well as a more recent record from that was confirmed during field investigations. The colony observed was located well above summer water levels, and both above and below flood elevations. This area remains without significant canopy cover due in part to bank flooding and in part to roadside maintenance. The New England Wildflower Society (Clark 2000) reports that typical habitat for this species includes disturbed habitats (roadsides, fields, and edges of streams), often in damp or alluvial soils. Wild Senna is classified as a facultative species in New England, which means it is equally likely to be found in uplands and wetlands. This plant may be partially dependent on floods to maintain canopy openings and for seed dispersal, but is not dependent on low or average flows. If water management alternatives considered in the Water Management Plan affect high flows, then potential impacts to this IPUOCR will be addressed in the WMP.

C. Natural Communities

The New Hampshire Natural Heritage Bureau (NHNHB) mapped several Natural Communities considered worthy of protection along the Souhegan River, and other Natural Communities and potentially important habitats were found during field surveys. Precise locations of rare or vulnerable elements in these Natural Communities and other elements identified by the NHNHB as sensitive or rare are not provided in this report; rather the general setting as it relates to river flow is described. Plant nomenclature follows Magee and Ahles 1999.

High Energy Riverbank (Twisted Sedge (*Carex torta*) Low Riverbank Community and Fern Glade)

Location and Description
The High Energy Riverbank community is located along portions of the upper Souhegan River below the Town of Greenville. The plant community in the vicinity of the habitat mapped by NHNHB is the Twisted Sedge Low Riverbank community (considered rare to locally abundant). This community is found anchored to the cobbly river margins just above the summer water level to an average 10 inches (maximum of 3 feet) above that level (Sperduto and Nichols, 2004). The river margin is scoured by high flows in spring and ice in winter. Transect R1 S6 T1 also includes this community as well as a Fern Glade (status unknown) that forms a narrow band on the sand deposits between the Twisted Sedge Low Riverbank and the hemlock-northern hardwood forest terrace above.

In addition to Twisted Sedge, dominant vegetation includes False Nettle (*Boehmeria cylindrica*) and Joe-Pye Weed (*Eupatorium maculatum*). The most common plants in the fern glade are Interrupted Fern (*Osmunda claytoniana*), New York Fern (*Thelypteris noveboracensis*), Sphagnum Moss and other bryophytes.

Evaluation Method
Flow requirements for the High Energy Riverbank Community were determined using the Floodplain Transect Method. This included a topographic survey of the channel and adjacent banks and floodplain; cover type mapping in the selected segment; and development of cross-sections with plant community boundaries and water levels at various flows (Appendix 16). Transect R1 S6 T1 represents this community.

Flow Requirements
These communities are adapted to daily and seasonal fluctuations in water levels, but permanent alterations to these plant communities could result from:

- Consistent reductions of summer low flows with no other seasonal changes, which could favorably expand the Twisted Sedge Low Riverbank Community downgradient;
- Consistent reductions in winter and spring flood levels and ice scour, which could alter plant composition in the Twisted Sedge Low Riverbank Community and Fern Glade thereby adversely decreasing these Natural Communities.

Median August flow at Site 1, to which the current vegetation is apparently well adapted, is approximately 6.8 cfs (0.04 cfsm) as derived from the relationship between the USGS station at the Merrimack and the concurrent measured flows at Site 1. A flow of 7.3 cfs was measured at Site 1 in August 2005, which was a relatively wet month. A consistent decrease in summer low water levels would likely expose additional cobble substrate, potentially allowing the expansion of the Twisted Sedge Low Riverbank Community into the channel, a favorable net increase. The upper edge of the Twisted Sedge low Riverbank community would still be within 1 meter of the summer water level, and would presumably be maintained by spring floods and winter ice scour, as would the Fern Glade. The potential increase in

Twisted Sedge low Riverbank area associated with summer flow reductions, extrapolating the transect data (Appendix 16) to an estimated 26,000 linear feet of riverbank on which it is found is approximately 3.6 acres.

Reductions in flows that also decrease the extent of annual spring highs and ice scour would perhaps allow a greater variety of herbaceous plants to become established in the lower channel, shifting the Twisted Sedge cover type to a more diverse association of herbaceous plants and possibly shrubs. This hydrologic regime also may allow woody plants to develop in the Fern Glade zone. Based on field observations of inundation, a reduction of winter and spring flows at Site 1 below approximately 500 cfs at the Merrimack Gauge (2.9 cfsm) for the duration of the December to April period would eliminate scouring of the Twisted Sedge community. The mean of monthly streamflow at the Merrimack Gauge in March and April (over 70 years of record) is 623 cfs and 776 cfs, respectively. There is an estimated 10 acres of Twisted Sedge Community and an estimated 2.4 acres of Fern Glade (assuming it is present only along the 13,000 feet of Site 1 with a well-shaded southern bank) that would be affected by consistent and prolonged winter/spring flow reductions.

Southern New England Floodplain Forest: Silver Maple *(Acer saccharinum)* Floodplain Forest

Location and Description

Within the Towns of Amherst and Merrimack, in the lower gradient portion of the Souhegan River, Silver Maple Floodplain Forests typical of medium and large rivers in the state were observed. The specific community present, the Silver Maple-False Nettle-Sensitive Fern variant, is considered imperiled state-wide due to rarity, and differs from the Silver Maple Floodplain Forests along the Connecticut River in having greater ground cover diversity, lower soil pH, sandier soil texture, and greater flooding duration and disturbance. The NHNHB mapped one such community along the banks of the Souhegan River in Merrimack. Smaller versions of this community are represented at Sites 8 and 10.

Evaluation Method

Silver Maple Floodplain Forests were mapped using the Floodplain Transect Method. This included a topographic survey of the channel and adjacent banks and floodplain; cover type mapping in the selected segment; and development of cross-sections with plant community boundaries and water levels at various flows. This community is represented on Floodplain Transects R6 S49-50 T1 and T2 and R7 S61 T1 (Appendix 16).

Flow Requirements

This low floodplain community depends on periodic (every 1-3 years or more frequently) flooding and scouring to provide nutrients and bare soil for seedling regeneration, and reduce competition from flood-intolerant plant species. Flooding of these areas occurred in April and October of 2005 with flows as low as 2,000 cfs (11.7 cfsm). The 2-year return interval flood is approximately 2,683 cfs (at Merrimack Gage). During the rest of the growing season, this community has a mesic moisture regime and is not dependent on low flows. Based on the typical flood regime for this community and observed flooding events, spring flows above 11.7 cfsm at least once every three years will be protective of this community.

Southern New England Floodplain Forest: Sycamore (*Platanus occidentalis*) Floodplain Forest

Location and Description

A Sycamore Floodplain Forest not mapped by the NHNHB is located on an island and floodplain terrace in the upper Souhegan River. Such communities are considered state-imperiled and rare, reaching their northern limit in southern New Hampshire and southern Maine. They are characteristically found on cobbly substrates with flashy streamflow (Sperduto and Nichols, 2004). Some of the other plants considered characteristic of this community were also observed, such as Sugar Maple (*Acer saccharinum*), Bitternut Hickory (*Carya cordiformis*) and Jumpseed (*Polygonum virginiana*). However, the understory in the island portion of the community was almost pure Sugar Maple, and several plant species considered invasive were common, including Purple Loosestrife (*Lythrum salicaria*) along the river edge, Japanese Bamboo (*Polygonum cuspidatum*) on the lowest floodplain terrace, and Honeysuckle (*Lonicera sp*.), Asian Bittersweet (*Celastrus orbiculata*), and Japanese barberry (*Berberis thunbergii*) in the higher locations. The abundance of Sugar Maple seedlings and saplings in the understory on the island indicates that the Sycamore canopy (Appendix 16) may eventually be replaced by Sugar Maple in this location. Sugar Maple is generally found on mid-level or higher floodplain terraces (Sperduto and Nichols 2004; Nislow et al. 2002). Young Sycamores were observed where flood flows scour the river edge indicating continued Sycamore regeneration in areas of frequent flooding and canopy openings, as seedlings require bare, moist soil and light to germinate and thrive. It is possible that the flood frequency in effect when the island canopy vegetation was established has been reduced to that of a higher floodplain terrace, which may be related to upstream dam construction and channelization.

Evaluation Method

The Sycamore Floodplain Forest was mapped using the Floodplain Transect Method. This included a topographic survey of the channel and adjacent banks and floodplain; cover type mapping in the selected segment; and development of cross-sections with plant community boundaries and water levels at various flows. This community is represented on Floodplain Transect R4 S28 (Appendix 16).

Flow Requirements

As with other low floodplain communities, the Sycamore Floodplain Forest is dependent on periodic (every one to three years) flooding and scouring to provide nutrients and reduce competition from flood-intolerant plant species. Low flows are less critical. The 2-year return interval flood is 2,683 cfs at the Merrimack Gage (15.7 cfsm). Flows of 2,000 to 3,000 cfs recorded in April of 2005 that flooded the Silver Maple Floodplain Forest downstream on the Souhegan River did not appear to flood the entire Sycamore island, but did flood other portions of the Sycamore stand. Periodic flows greater than 3,000 cfs (17.5 cfsm) may provide some favorable sites for Sycamore regeneration on the island.

Oxbow/Backwater Marsh

Location and Description

Oxbow and backwater marshes are present along the low-gradient portions of the Souhegan below the Town of Milford in Amherst and Merrimack. These marshes are typically in old meander scars or behind natural levees partially filled in with sediments. They are often shallower than the adjacent river and connected to it through outlets that may be constricted. Marshes develop only in the oxbows and backwaters sufficiently wide to allow full sun exposure; otherwise they are floodplain pools with forested cover. The NHNHB did not provide maps of these habitats, but considers these habitats rare and/or local in the State or vulnerable for other reasons

Marsh vegetation is generally well adapted to short-term water level fluctuations, but susceptible to drowning or desiccation during prolonged floods or droughts. Concentric rings of vegetation were commonly observed to correspond to the water level gradient, with Reed Canary Grass (*Phalaris arundinacea*) and Purple Loosestrife on the highest edges; Water Parsnip (*Sium suave*), Rice Cutgrass (*Leersia oryzoides*), Buttonbush (*Cephalanthus occidentalis*), Three-way Sedge (*Dulichium arundinaceum*) and Spikerush (*Eleocharis* sp.) below that; Arrowhead (*Sagittaria latifolia*), Pickerelweed (*Pontederia cordata*), Burreed (*Sparganium* sp.) and Mild Water Pepper (*Polygonum hydropiperoides*) as the deepest emergents; and Waterweed (*Eleodea Canadensis*), Coontail (*ceratophyllum demersum*), and Yellow Water Lily (*Nuphar lutea*) as submerged and floating-leaved aquatics in the deepest vegetated zone.

The marshes typically fill in spring as the lower floodplain floods, draining slowly during the summer months until only the deeper marshes contain standing water, and surface connections to the river may be temporarily lost. Since floodplains are dynamic, both water levels and the arrangement of sediments and plants are always changing. The oxbow marshes observed on the Souhegan vary in their stability and flow dependence.

For example, the oxbow marsh at Site 8 included three marsh basins separated by shallow intervals. These marshes fill in spring as the floodplain floods. As water levels drop during the typical summer, the basins farthest from the river are reduced to small, disconnected pools surrounded by dense vegetation. The basin closest to the river drains more completely as the river levels drop below the basin outlet elevation. This basin is therefore more dependent on low river flows than the other basins. The oxbow marsh at Site 10 has a deeper channel connection directly to the Souhegan River, and would drain more completely during lower flows. In contrast, an emergent/shrub back swamp at Site 10 has a beaver dam at its outlet, and water levels remained relatively constant throughout the growing season regardless of River flows. The hydrology and vegetation may change when the dam falls into disrepair, a natural cycle along a river.

Evaluation Method

Flow requirements for the Oxbow and Backwater Marshes were determined using the Floodplain Transect Method. This included a topographic survey of the channel, adjacent banks, marshes and floodplain; cover type mapping in the selected segment; and development of cross-sections with plant community boundaries and water levels at various flows. Sites 8 and 10 have oxbow marshes, which are represented on Floodplain Transects R6 S49-50 T-2 and R7 S61 T-2 (Appendix 16). This information was extrapolated to the entire lower Souhegan River (below Milford) based on digitized National Wetland Inventory mapping, by querying the area of different wetland types within 500 feet (includes most floodplain areas) of the lower Souhegan River (except those identified as having beaver modified hydrology). In addition, the MesoHABSIM model figures were consulted to identify which oxbows and backwaters were drained at selected target flows.

<u>Flow Requirements</u>
The following general long-term conditions were considered necessary to maintain the approximate quantity and distribution of marsh vegetation in the oxbows/backwaters:

- high spring flows to fill the marshes;
- slowly declining water levels May through September;
- sufficient water May through September to prevent rhizome desiccation.

Based on the floodplain cross sections it was determined that should summer water levels be permanently reduced below those observed in August 2005 (31 to 47 cfs) for the entire summer (June-September), the emergent marshes with direct river connections would be partially dewatered. This would result in vegetation stress and over the long term, a substantial reduction in aquatic bed and deep emergent habitat and an increase in forest, shrub and shallow emergents. Further reductions in flow below these levels for the entire growing season (including lack of spring flooding) could also reduce overall marsh acreage. These effects could also occur if the oxbows fail to fill in spring.

The potential shifts in cover type areas associated with reduced summer water levels or failure to fill were calculated from the measured community widths on the transects and cover type maps. Extrapolating this information to the entire lower Souhegan River using NWI data, 100% of the total area of aquatic bed oxbow wetlands (0.12 acres) would be lost; the 11.42 acres of forested wetlands on the lower floodplain terrace could increase by approximately 5 acres (45%); and the area of emergent wetlands (currently 6.39 acres) could increase or decrease, depending on landscape position. This numerical extrapolation is only broadly applicable, given that:

- each marsh has a unique river connection and landscape position that may make it more or less flow dependent than the evaluated marshes;
- NWI maps are not as accurate as on-the-ground surveys;
- some of the NWI wetlands are probably not oxbows, but may be associated with tributaries or back swamps; and
- small wetland vegetation increases in shallow channel margins may partially offset losses in oxbows.

The general assumptions about changes in cover types are relevant, and would be expressed differently at each particular location. To maintain the current balance of wetland types along the lower Souhegan River, spring flows greater than 600 cfs (3.5 cfsm) must occur in most years to fill the oxbows and backwater marshes, even if for short duration. Summer flows above 30 cfs (0.18 cfsm) for at least a portion of the June to September summer season will prevent the loss of deep marsh vegetation.

IX.) Environmental/Fish Habitat

Target Fish Community Development

The status of the Souhegan River fish community was evaluated using the Target Fish Community (TFC) approach developed by Bain and Meixler (2000). A TFC represents the expected fish community if there were few or no impairments in a watershed. Two separate target fish communities were developed for the Souhegan River using a GIS based method of selecting reference quality rivers that were physically and zoogeographically similar to the upper and lower Souhegan River. Fish data from these reference rivers were then used to compute the expected proportions of fish within the Target Fish Communities using the rank-weighted technique developed by Bain and Meixler (2000). The existing fish faunas of the Souhegan River were then compared to the TFC using a Percent Model Affinity procedure developed by Novak and Bode (1992) to evaluate the status of the fish faunas within the upper and lower portions of the Souhegan River. For more detail on the upper and lower Souhegan TFC development process refer to Appendix 6.

Upper Souhegan River Target Fish Community

The upper Souhegan River TFC was created using fish collection data from eleven quality reference rivers as described in Appendix 6. The resulting community of 18 species was diverse but dominated by fluvial species. The ten most abundant species in the TFC were blacknose dace (29%), longnose dace (15%), common shiner (10%), white sucker (7%), fallfish (6%), slimy sculpin (5%), Eastern brook trout (4%), longnose sucker (4%), redbreast sunfish (3%), and Atlantic salmon (3%). The remaining species consisted of brown bullhead, creek chub, yellow perch, pumpkinseed sunfish, golden shiner, Eastern chain pickerel, spottail shiner, and American eel, and accounted for a combined total of 14% of the expected community with individual proportions ranging between 1% and 2%.

Lower Souhegan River Target Fish Community

The lower Souhegan River TFC was created using fish collection data from five quality lower reference rivers as described in Appendix 6. The TFC was as equally diverse as the upper TFC. It had 17 species and was also dominated by fluvial species. The ten most abundant species in the lower TFC were white sucker (30%), fallfish (15%), common shiner (10%), blacknose dace (8%), longnose dace (6%), yellow perch (5%), pumpkinseed sunfish (4%), brown bullhead (3%), tessellated darter (3%), and Eastern chain pickerel (3%). The remaining species, redbreast sunfish, golden shiner, creek chubsucker, American eel, spottail shiner, and Eastern brook trout, account for a combined total of 12% of the expected community with individual proportions ranging between 1% and 2%.

Fish and Invertebrate Sampling

In an effort to evaluate the status of the instream fauna of the Souhegan River, instream surveys were conducted on the fish and invertebrate communities of the upper and lower river.

In July and August 2005, fish were sampled using pre-positioned electrofishing grids (Bain, 1985) in the upper river (Reaches 1-3) and within suitable (less that 1 m water depth) sections of representative site 7 (Reach 5) on the lower river. The majority of the lower river however, consisted of depths unsuitable for this method of electrofishing and was surveyed through underwater observations of fish while snorkeling. Snorkel surveys occurred in August and September 2005 within previously selected hydromorphologic units or habitat types that were, as a whole, representative of each sampling site and the lower segment of the river.

Evaluation of the invertebrate community within the Souhegan River consisted of a freshwater mussel survey and sampling of aquatic insects to identify individual species of mussels and odonates within the river. The desire was to create an experimental model capable of identifying suitable habitat and instream flow requirements for these organisms. See Appendix 7 for more detail.

Existing Fish Community

Upper Souhegan River fish community

The existing fish community of the upper segment of the Souhegan River, as sampled in the summer of 2005, was dominated by blacknose dace (55%), longnose dace (25%), fallfish (6%), common shiner (5%), white sucker (3%), yellow perch (2%), largemouth bass (2%), Atlantic salmon (1%). The Upper Souhegan fish community consisted of native fluvial species (94%), with a small proportion of macrohabitat generalists (5%). Pumpkinseed, golden shiner, and brown trout, combined, comprised the remaining 1% of the community. A total of 11 different fish species were sampled in the upper segment of the Souhegan River, 9 of which were native. The only two non-native fish species sampled in the upper Souhegan, largemouth bass and brown trout, accounted for less than 3% of the community.

Lower Souhegan River fish community

The existing fish community of the Lower Souhegan River, also surveyed in the summer of 2005, was dominated by common shiner (30%), fallfish (20%), blacknose dace (16%), white sucker (13%), redbreast sunfish (13%), longnose dace (4%), largemouth bass (2%) and golden shiner (1%). The lower Souhegan fish community consisted of primarily native fluvial species (84%), with a considerably lesser proportion of macohabitat generalists (16%). Yellow bullhead, brown trout, creek chubsucker, chain pickerel, yellow perch, bluegill, rainbow trout, and pumpkinseed accounted for a combined total of less than 2% of the community. A total of 16 different fish species were sampled in the Lower Souhegan River, 11 of which were native. The five non-native species sampled in the Lower Souhegan, largemouth bass, yellow bullhead, brown trout, bluegill, and rainbow trout accounted for a combined total of less than 3% of the community.

Existing Invertebrate Community

Upper Souhegan River mussel community

In the fall of 2004 multiple habitat types were surveyed in the Upper Souhegan River. Representative sites 1, 2, 3, 4, and 5 were surveyed with 128 quadrates placed at random locations throughout various hydromorphological unit (HMU) types representative of the upper river. The 2004 survey did not locate any freshwater mussels in any of the habitat units that were sampled.

Lower Souhegan River mussel community

The 2005 mussel survey of the Lower Souhegan River resulted in the location of 71 mussels originating from 27 of the 93 quadrates sampled. The three different species of freshwater mussels that were located and identified during these surveys were triangle floater (*Alasmidonta undulata*) (3%), Eastern elliptio (*Elliptio complanata*) (94%), and creeper (*Strophitus undulatus*) (3%). Densities within a quadrate ranged from 1-14 mussels. The quadrate containing the highest density of mussels (n=14) was located within our representative site 7 which also contained the highest density of mussels found within a site (n=32). Site 7 did not however, exhibit a diversity of species, as all 32 specimens sampled were Eastern elliptio. Triangle floater were found along with Eastern elliptio within representative site 10, and observations of single creeper specimens were found, also along with Eastern elliptio within representative sites 8 and 9. Eastern Elliptio occurred within every representative site of the Lower Souhegan River.

Upper Souhegan River odonate community

Odonate samples were collected from representative sites 1, 2, 3, and 5 on the Upper Souhegan River during the fall of 2004. A total of 52 individuals of the Odonatae family were collected from 34 of the 100 quadrates sampled. Odonates were collected from all representative sites that were sampled. The maximum number of odonates collected from a single quadrate was three. Of the 52 individuals collected, representative site 1 accounted for 29%, site 2 for 28%, site 3 for 31%, and site 5 for only 12% of the total number of odonates collected.

Lower Souhegan River odonate community

Odonate samples were collected from representative sites 6, 7, 8, 9, 10, and 11 on the lower segment of the Souhegan River during the fall of 2005. A total of 60 individuals of the Odonatae family were collected from 33 out of the 93 quadrates sampled. The maximum number of odonates collected from a single quadrate was five. Of the 60 individuals collected, representative site 6 accounted for 22%, site 7 for 30%, site 8 for 12%, site 9 for 20%, site 10 for 13%, and site 11 for 3% of the total number of odonates collected.

Comparison of TFC to the Existing Souhegan River Fish Community

Percent model affinity

Evaluation of the status of the fish fauna in the Souhegan River was accomplished using a direct similarity comparison between the TFC and the Souhegan River fish community as sampled in 2005. This procedure yields values from 0 to 100 to describe the extent to which the Souhegan River fish community is similar to the TFC. The higher the yielded percent model affinity value, the higher the degree of similarity between the communities. These values are calculated as:

$$\text{Percent similarity} = 100 - 0.5\ (\text{Sum}\left|\text{target P} - \text{observed P}\right|)$$

where: P = proportions of each species in the community or collection

Under-represented species, over-represented species, and introduced or non-native species within the Souhegan River were also identified based on their relationship to expected proportions identified in the TFC. Additional comparisons were made between the proportions of habitat use classification guilds within the two communities. Similarly, pollution tolerance and thermal regime tolerances classification guilds were compared.

Habitat Use, Pollution Tolerance, Thermal Regime Classification Guilds

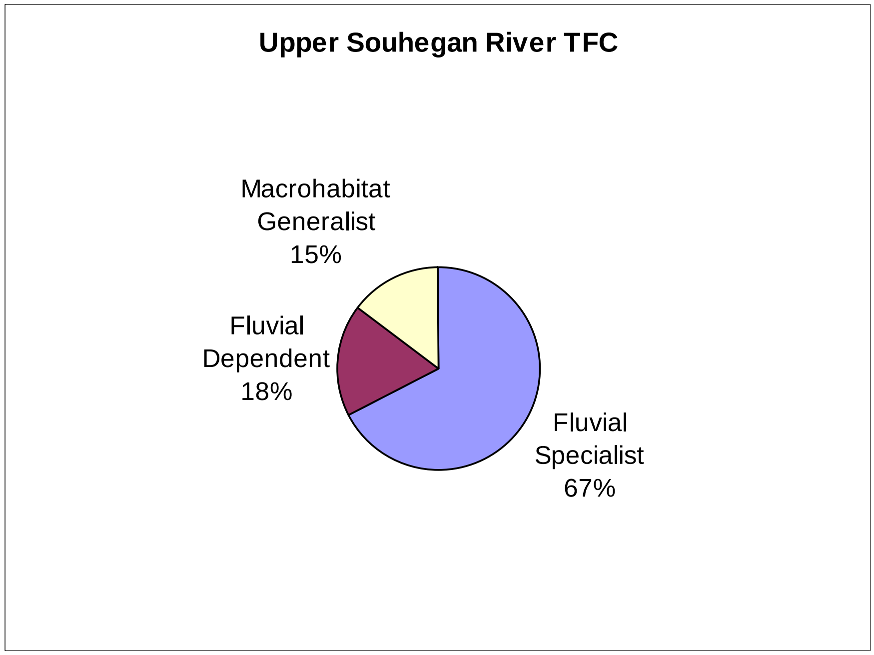
The fish species within the TFC and the Souhegan River existing fish communities were organized into specialized habitat use and pollution tolerance classification guilds based on classifications assigned by Bain (2000). Creek chub, fallfish, longnose dace, longnose sucker, and slimy sculpin were reclassified as fluvial specialists in this study, as in previous target fish community studies within this region based on their local habitat use patterns (Lang et al., 2001; Kearns et al., 2005). Fish species were also classified based on their thermal regime specifications. These were assigned based on a review of the literature pertinent to the fishes of the northeast region (Scarola, 1987; Hartel et al. 2002; NAI, 2004; Halliwell et al., 1999).

Upper Souhegan River habitat use guilds

The upper TFC consisted of 67% fluvial specialist, 18% fluvial dependent, and 15% macrohabitat generalist species. The Upper Souhegan River existing fish community consisted of 87% fluvial specialist, 8% fluvial dependent, and 5% macrohabitat generalist species (Figure 12).

Lower Souhegan River habitat use guilds

The lower TFC consisted of 35% fluvial specialist, 42% fluvial dependent, and 23% macrohabitat generalist species. The Lower Souhegan existing fish community was comprised of 41% fluvial specialist, 43% fluvial dependent, and 16% macrohabitat generalist species (Figure 13).



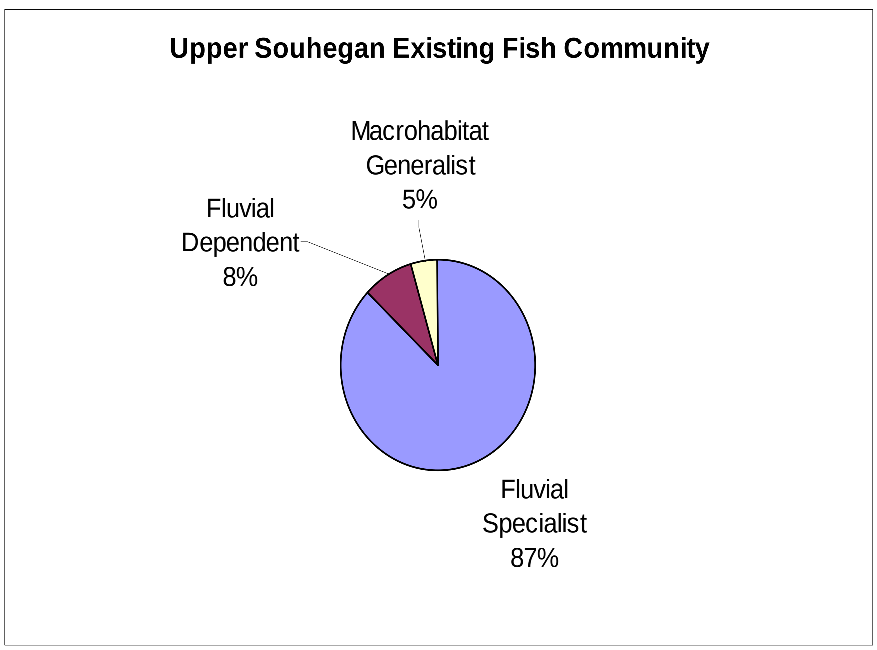
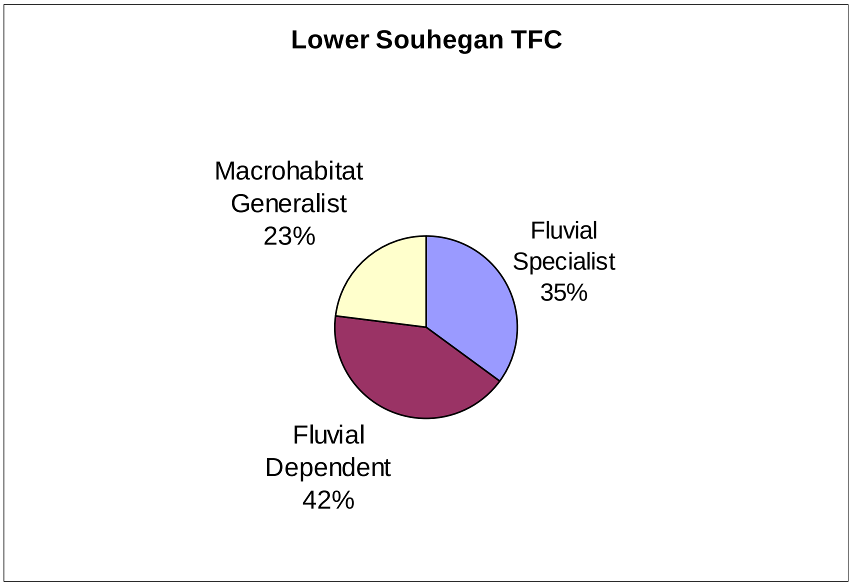


Figure 12. Percentages of Upper Souhegan River TFC and existing fish community species by habitat use classification guilds.

Comparison of Species Within the TFC and the Existing Fish Communities

Differences between proportions of individual species in the TFC and the existing fish communities of the Souhegan River were analyzed to evaluate the status of individual fish species within the river. The analysis of deviations was used to determine fish species that were under-represented, existing in expected proportions, overly abundant, or absent in the Upper Souhegan River. Species with proportions 50% lower than expected were considered underrepresented and species with proportions 30% higher than expected were considered overabundant. The presence of non-native or introduced fish species and their proportion of the existing community were also identified.



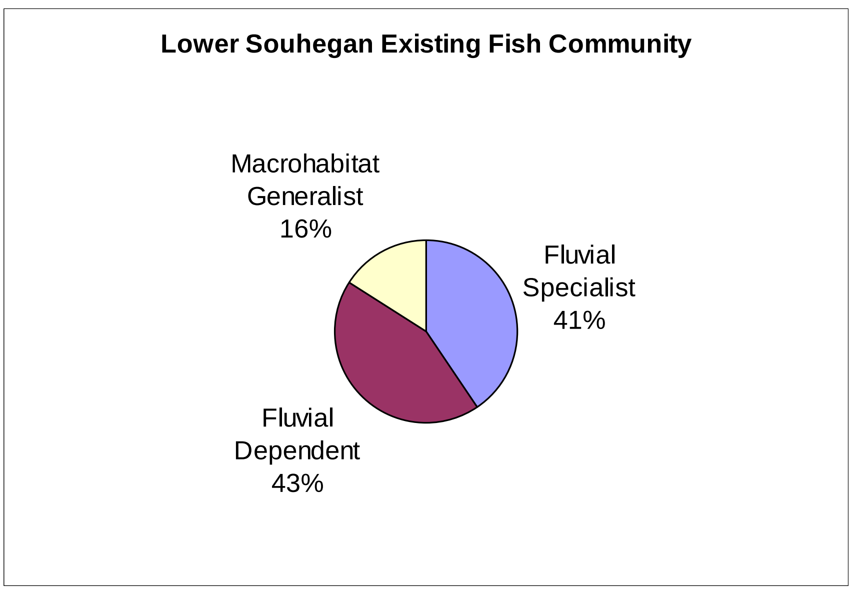


Figure 13. Percentages of Lower Souhegan River TFC and existing fish community species by habitat use classification guilds.

Table 14. Comparison of proportions of fish species between the TFC and Upper Souhegan River existing fish community identifying under-represented, existing as expected, overly abundant, missing, and introduced species in the upper Souhegan River. Native (N) or introduced (I) statuses, fluvial specialist (FS), fluvial dependent (FD), or macrohabitat generalist (MG) habitat use classifications, intolerant (I), moderate (M), or tolerant (T) pollution tolerances, and Cold, Cool, or Cold water thermal regimes are given for each species.

Species	Proportion of Target Fish Community	Proportion of Existing Fish Community	Native or Introduced	Habitat use Classification	Pollution Tolerance	Thermal Regime
Underrepresented native target fish species						
Atlantic salmon	3%	1%	N	FS	I	Cold
Common shiner	10%	5%	N	FD	M	Cool
Golden shiner	2%	<1%	N	MG	T	Cool
Pumpkinseed	2%	<1%	N	MG	M	Warm
White sucker	7%	3%	N	FD	T	Cool
Target fish species recorded as expected						
Fallfish	6%	6%	N	FS	M	Cool
Yellow perch	2%	2%	N	MG	M	Cool
Overly abundant native target fish species						
Blacknose dace	29%	55%	N	FS	T	Cool
Longnose dace	15%	25%	N	FS	M	Cool
Missing native target fish species						
American eel	1%	0%	N	FD	T	Cool
Brown bullhead	2%	0%	N	MG	T	Warm
Chain pickerel	2%	0%	N	MG	M	Warm
Creek chub	2%	0%	N	FS	T	Cool
Eastern brook trout	4%	0%	N	FS	I	Cold
Longnose sucker	4%	0%	N	FS	M	Cold
Redbreast sunfish	3%	0%	N	MG	M	Warm
Slimy sculpin	5%	0%	N	FS	I	Cold
Spottail shiner	1%	0%	N	MG	M	Cool
Introduced species present in the existing fish community						
Brown trout	0%	<1%	I	FD	I	Cool
Largemouth bass	0%	2%	I	MG	M	Warm

* The expected proportion of Atlantic salmon is most likely lower than under natural conditions. The reason is that none of the reference rivers have this species in natural proportions

Upper Souhegan River species comparison

Atlantic salmon, common shiner, golden shiner, pumkinseed and white sucker were determined to be under-represented in the Upper Souhegan community, while blacknose dace and longnose dace were found in greater proportions than predicted target community proportions. Brown trout and largemouth bass represented the only two non-native or introduced species in the Upper Souhegan fish community (Table 14).

Lower Souhegan River species comparison

In the lower community chain pickerel, creek chub sucker, pumpkinseed, yellow perch and white sucker were found to be under-represented, while blacknose dace, common shiner and redbreast sunfish were considered to be over-represented. Introduced species existing in the Lower Souhegan River were bluegill, brown trout, largemouth bass, rainbow trout, and yellow bullhead (Table 15).

Table 15. Comparison of proportions of fish species between the TFC and Lower Souhegan River existing fish community identifying under-represented, existing as expected, overly abundant, missing, and introduced species in the upper Souhegan River. Native (N) or introduced (I) statuses, fluvial specialist (FS), fluvial dependent (FD), or macrohabitat generalist (MG) habitat use classifications, intolerant (I), moderate (M), or tolerant (T) pollution tolerances, and Cold, Cool, or Cold water thermal regimes are given for each species.

Species	Proportion of Target Fish Community	Proportion of Existing Fish Community	Native or Introduced	Habitat use Classification	Pollution Tolerance	Thermal Regime
Underrepresented native target fish species						
Chain pickerel	3%	<1%	N	MG	M	Warm
Creek chubsucker	2%	<1%	N	FS	I	Cool
Pumpkinseed	4%	<1%	N	MG	M	Warm
Yellow perch	5%	<1%	N	MG	M	Cool
White sucker	31%	13%	N	FD	T	Cool
Target fish species recorded as expected						
Fallfish	15%	20%	N	FS	M	Cool
Golden shiner	2%	1%	N	MG	T	Cool
Longnose dace	6%	4%	N	FS	M	Cool
Overly abundant native target fish species						
Blacknose dace	8%	17%	N	FS	T	Cool
Common shiner	10%	30%	N	FD	M	Cool
Redbreast sunfish	2%	13%	N	MG	M	Warm
Missing native target fish species						
American eel	2%	0%	N	FD	T	Cool
Brown bullhead	3%	0%	N	MG	T	Warm
Eastern brook trout	1%	0%	N	FS	I	Cold
Spottail shiner	2%	0%	N	MG	M	Cool
Tessellated darter	3%	0%	N	FS	M	Cool
Introduced species present in the existing fish community						
Bluegill	NA	<1%	I	MG	T	Warm
Brown trout	NA	<1%	I	FD	I	Cool
Largemouth bass	NA	2%	I	MG	M	Warm
Rainbow trout	NA	<1%	I	FD	I	Cold
Yellow bullhead	NA	<1%	I	MG	T	Warm

Comparison of TFC and Existing Community Species to Souhegan River Suitable Habitat Availability

Habitat suitability criteria were used to determine the proportions of suitable habitat available for Souhegan River fish species. These habitat proportions were then compared to the predicted and existing proportions of fish species for the river to identify instances where habitat may possibly be a limiting factor in the existing proportions of fish species.

Upper Souhegan River

Two species considered as under-represented in the existing fish community, common shiner and white sucker were found to exist in proportions similar to the proportions of available habitat at the three flow scenarios. These species may be limited by habitat availability on the upper Souhegan River. The habitat increases with flow for brook trout, a species missing from the Souhegan River fish community, existed in considerable proportions at all three flows. Based on this analysis, habitat did not seem to be the primary factor explaining the absence of brook trout from the Upper Souhegan River. Blacknose dace, fallfish, and longnose dace did not appear to be limited by habitat (Figure 14).

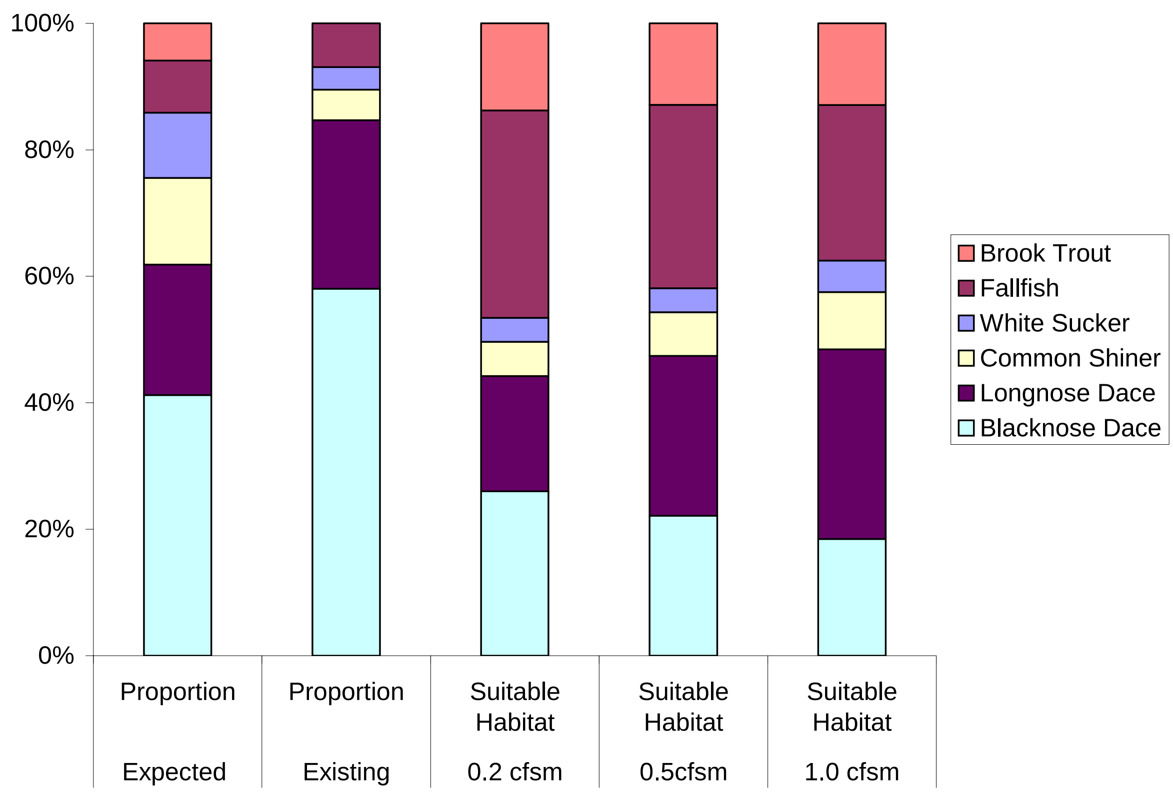


Figure 14. Comparison of proportions of fish species and their suitable habitats for the Upper Souhegan River.

Lower Souhegan River

The only under-represented fluvial species present on the Lower Souhegan River, white sucker, did not appear to be limited by habitat. An appreciable amount of suitable habitat was available for this species on the lower river. Likewise, brook trout, a species missing from the existing fish community of the Lower Souhegan River, seemed to have amounts of suitable habitat sufficient to support expected proportions predicted by the TFC. Conversely, proportions of longnose dace in the lower river could be limited by the amount of suitable habitat available. Blacknose dace, common shiner, and fallfish did not seem to be affected by habitat limitations on the lower Souhegan, as proportions exist in higher or similar proportions to the TFC (Figure 15).

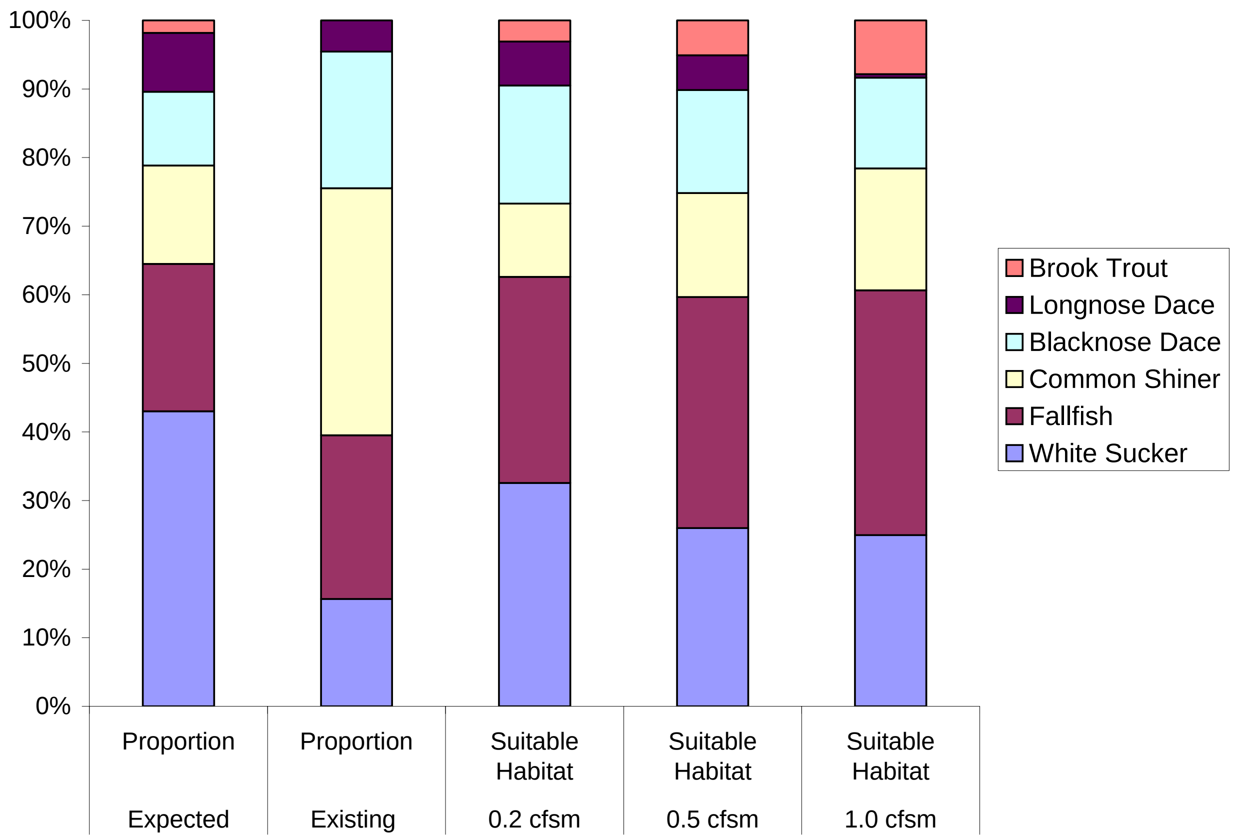


Figure 15. Comparison of proportions of fish species and their suitable habitats for the Lower Souhegan River.

Indicator Species

With the exception of over-wintering and spring flood seasons, the habitat model refers to the habitat used by the actual community present in a bio-period. After analysis of the TFC for each bio-period, a group of species representing the aquatic community was specified. Hence, the habitat needs for the rearing and growth bio-period were represented by a select group of species dominating the TFC. These fish were referred to as generic resident adult fish (GRAF) and young-of-the-year life stage (YOY). In addition the habitat needs of diadromous species (American eel, juvenile Atlantic salmon), underrepresented fish species (brook trout and slimy sculpin), freshwater mussels, and odonates have been taken into consideration. Those species were referred to as Special Interest Fish and Invertebrates (SIFI). During the spring spawning season the habitat needs of the anadromous Clupeids (American shad, alewife) and resident fauna were analyzed jointly. In the fall season the needs of resident fish were combined with those of the spawning life stage of Atlantic salmon. Habitat models have been developed for all of the above groups to determine the flow sensitivity of their habitat. The species (or species groups) with flow dependent habitat were selected as indicators for a season or bio-period.

Upper and Lower Souhegan indicator species

For the Upper Souhegan species selected to compose the GRAF group consist of longnose dace, blacknose dace, common shiner, fallfish, and white sucker. The slimy sculpin, Atlantic salmon, brook trout, mussels and odonates were selected to create the SIFI group. For Lower Souhegan the same species serve as GRAF. Slimy sculpin is not included in the SIFI group for the lower segment of the river but all other species within the SIFI group for the Upper Souhegan are the same for the Lower Souhegan.

Habitat Suitability Criteria

For each selected species and group of species two types of habitat suitability criteria were employed. For conditions where collection of empirical data was limited or impossible, available literature and professional judgment were used to develop a list of physical criteria associated with suitable habitat for indicator species. For conditions where adequate empirical data existed, these data were used to select criteria associated with habitat suitability and develop a model to identify levels of suitability of the previously mapped mesohabitats of the Souhegan River.

Due to the lack of empirical data for GRAF and SIFI spawning habitat suitability, a literature-based spawning habitat model was developed based on four habitat attributes. The spawning requirements of GRAF species and two SIFI species (Atlantic salmon and American shad) with regard to these four habitat attributes: depth, velocity, choriotop (substrate type), and HMU type, were researched. Criteria, values, and ranges were selected for each attribute that was indicative of suitable spawning habitat for a selected species. A spawning model was then created that would identify suitable spawning habitats for each species based on the presence of selected habitat attributes that meet the requirements of a particular species (Appendix 8).

The empirical set of criteria for R&G (rearing and growth) season had been developed from habitat use data collected in earlier studies for resident adult fish, SIFI and YOY. The fish habitat data collected on the Pomperaug River (196 grids), Eightmile River (350 grids) and Fenton River (500 grids) in Connecticut were analyzed with the help of a multivariate statistical model (logistic regression) to compute the habitat selection criteria for adult resident fish species and SIFI (for details on this method please see Appendix 8). The model selects habitat attributes corresponding with presence and abundance of the species that are then used to calculate probability of presence and high abundance in the surveyed mesohabitats. Unsuitable, suitable, and optimal habitats, corresponding with high probabilities of fish absence, presence, and high abundance, respectively, were distinguished. For YOY habitat, which consists only of shallow margins, empirical criteria developed on the Quinebaug River were applied.

Habitat Data Collection

The surveys of representative sites were repeated three times at conditions representing low summer flows determined by analysis of hydrologic time series obtained from the USGS gage in Merrimack, NH. The range of flows was defined using the Indicators of Hydrological Alteration (Richter et al. 1997) between 0.1 cfsm and 1 cfsm. This was also expected to roughly encompass the range of fish behavior associated with low flows. For our three surveys we targeted flows corresponding with 0.1 cfsm, 0.5 cfsm and 1 cfsm (+/- 10%) readings at the Merrimack gage. The actual flows at each site were determined from power law functions obtained from concurrent flow measurements (see Appendix 3).

Mapping

Figure 16 presents the timing and flows during the habitat surveys. The majority of the surveys took place in summer 2005. Three measurements for each site were completed with the exception of site 11. Because of very flashy flow conditions in the Souhegan River during summer 2005, the window of opportunity for mapping of the river at the flows of 1 cfsm was very limited (Figure 16) and therefore site 11 was not be mapped at this flow. Consequently it was decided to limit the analysis of the Lower Souhegan to the area upstream of Wildcat Falls. The section downstream of Wildcat Falls, represented by site 11, was analyzed separately at the two lower flows only (Appendix 8).

Rating Curves for Sites

The habitat quality in the sites was evaluated using criteria established as described in the previous paragraphs. The habitat suitability for all investigated species was calculated for each HMU, species, and life stage. Subsequently the HMUs were assigned to one of the above categories (unsuitable, suitable, optimal). The relative area of suitable and optimal habitat was determined for each site and flow and converted to habitat rating curves for every species and GRAF. The latter was computed by using the sum of habitats for GRAF species weighted by their expected proportions in the TFC. For species where an optimal habitat model could be established we computed the habitat area by weighting suitable habitat with 25% and optimal with 75% and adding them. For other species only suitable habitat was evaluated. The rating curves for the sites were generalized to Reaches.

To complement the assessment of the status of the fish fauna we also computed the structure (proportions) of habitat available for GRAF in each segment. The comparison with structure of the TFC and XFC allowed us to determine if habitat was potentially a limiting factor in fish abundance, specifically for species with flow sensitive habitats.

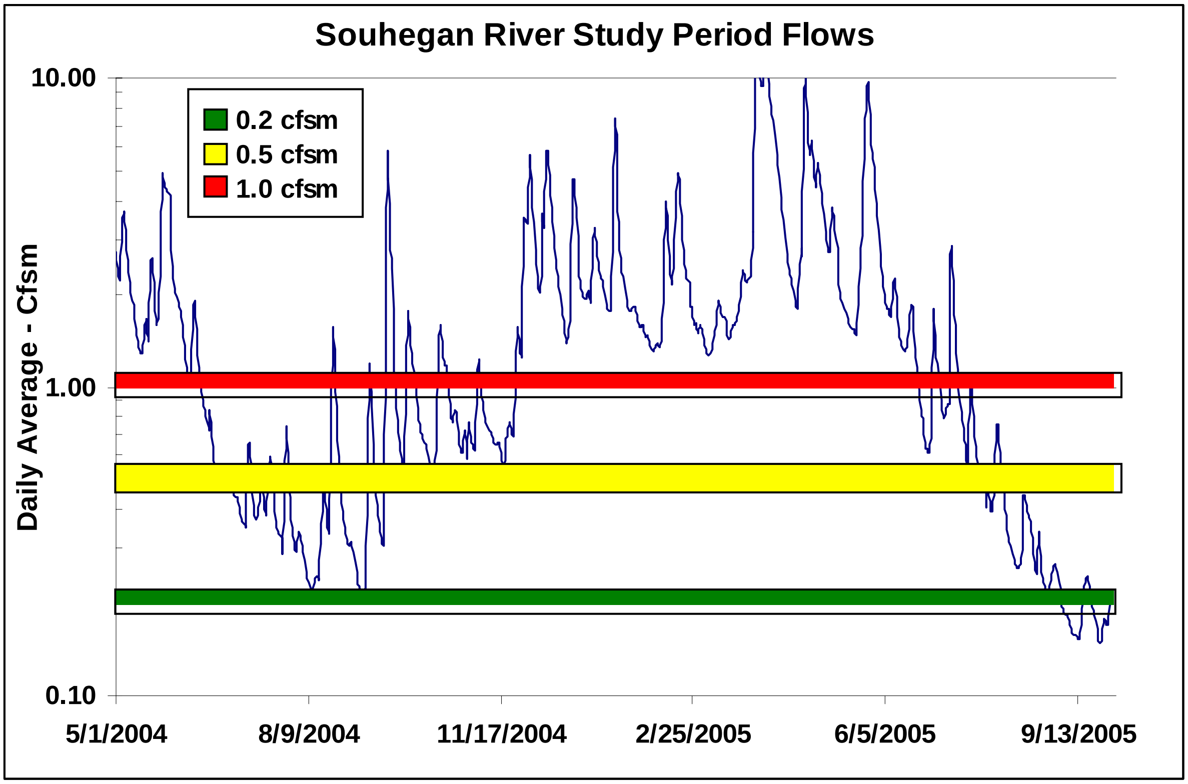


Figure 16. Hydrograph for the USGS stream gage at Wildcat Falls for the duration of the hydromorphological mapping period. The area shaded in green shows the river flow within 10% of 0.2 cfsm. The area shaded in yellow shows the river flows within 10% of 0.5 cfsm. The area shaded in red shows the river flows within 10% of 1.0 cfsm.

Reach 1

Rearing and Growth Bio-period

Atlantic salmon, American eel, slimy sculpin, YOY, and GRAF had increasing habitat area availability with flow until approximately 0.4 cfsm where they then remained stable. Brook trout decreased slightly with flows over 0.25 cfsm, but was largely non-flow dependant. There was no available odonate habitat in this study reach. American eel had the greatest available habitat, reaching 80% at flows over 0.3 cfsm. Atlantic salmon gained the most habitat area, increasing from 0% at 0.1 cfsm to 40% at 0.4 cfsm (Figure 17).

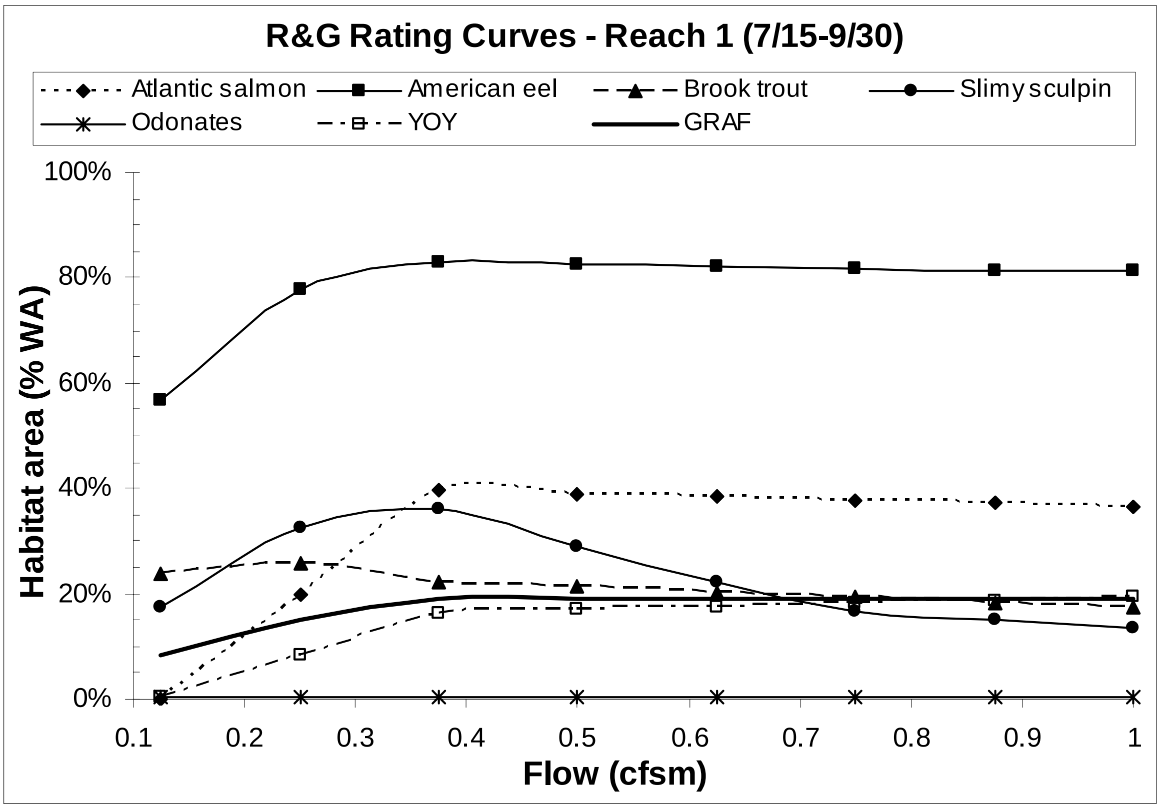


Figure 17. Habitat Rating curves for Reach 1 species during the R&G bio-period.

Spawning

Blacknose dace, common shiner, longnose dace, and GRAF had increasing habitat area availability with flow until around 0.4 cfsm where they then remained stable. Fallfish habitat area decreased slightly with flow, but was largely non-flow dependant. White sucker had the greatest available habitat area, reaching 47% at flows of 0.28 cfsm before slowly decreasing with increasing flows. Longnose dace gained the most habitat area, increasing from 10% at 0.1 cfsm to 23% at 0.4 cfsm (Figure 18).

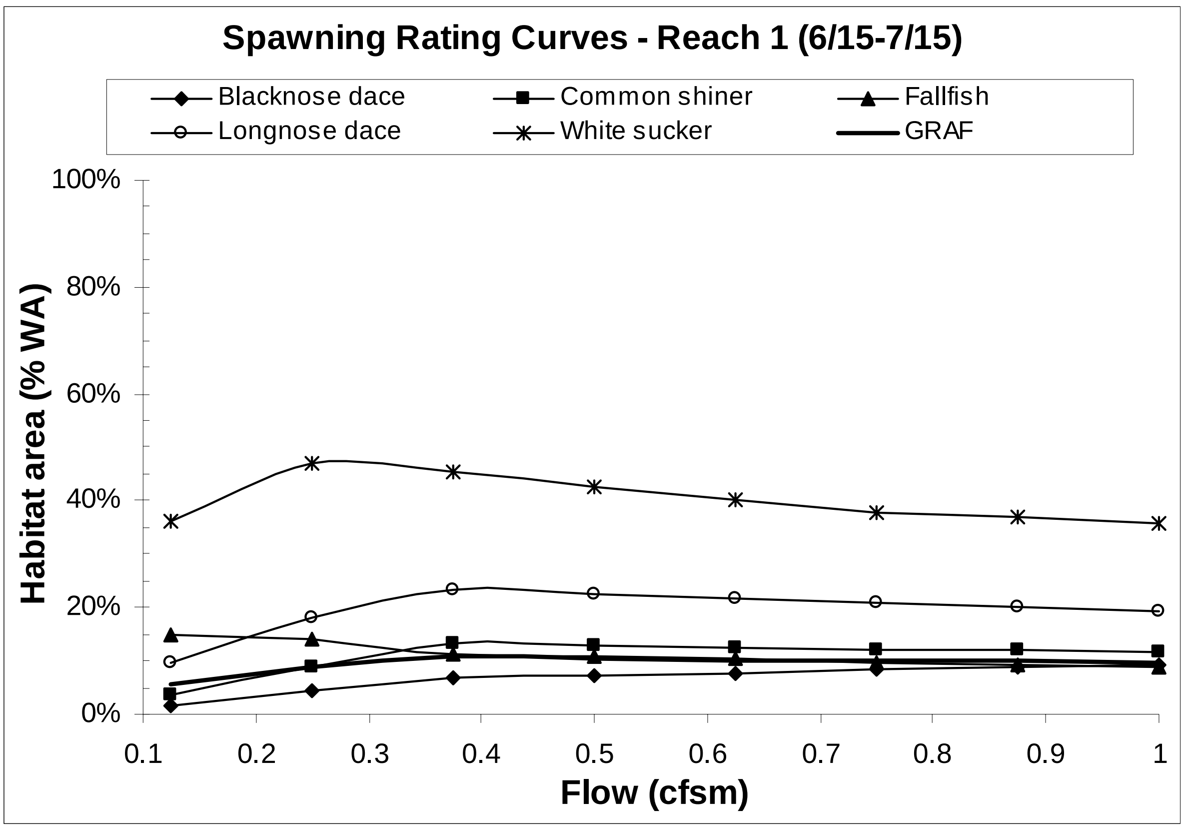


Figure 18. Habitat Rating curves for Reach 1 species during the Spawning bio-period.

Anadromous Spawning

Atlantic salmon and American shad habitat area both decreased slightly with increasing flow from 0.1 to 0.4 cfsm, at which point they each gained habitat area. American shad gained the most habitat area, increasing from 8% at 0.4 cfsm to 35% at 1.0 cfsm (Figure 19).

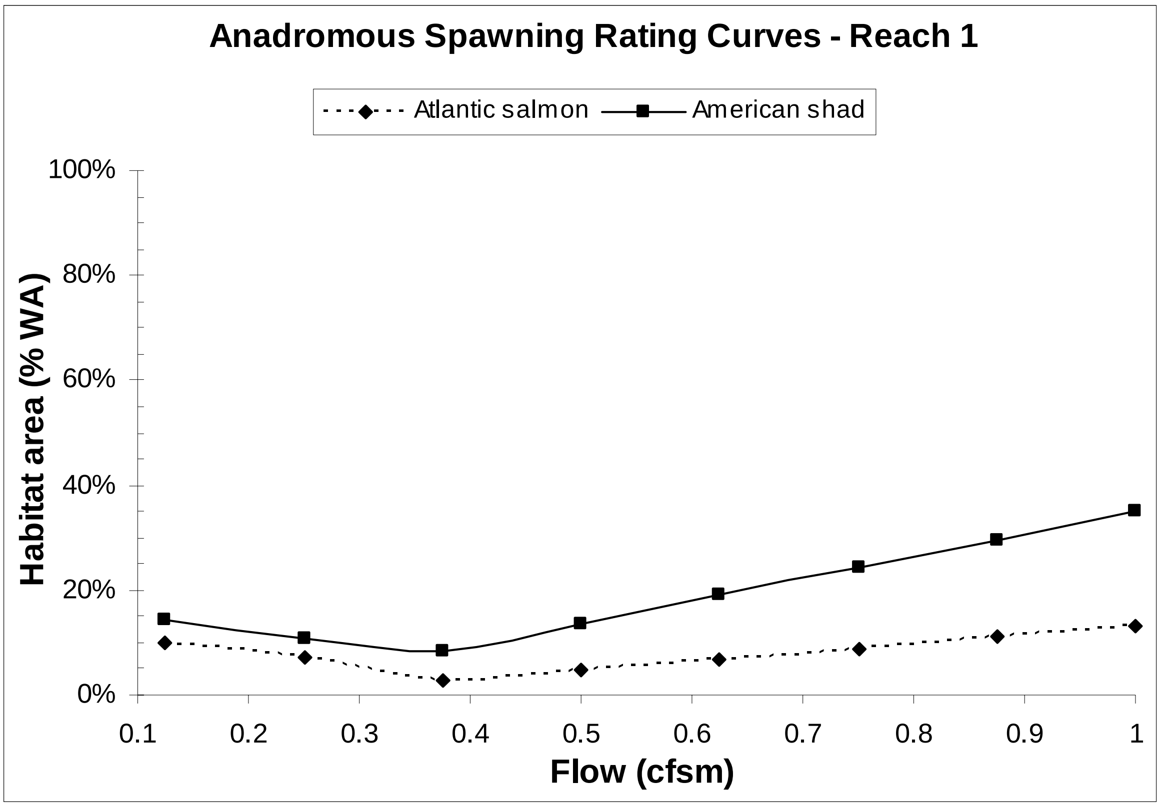


Figure 19. Habitat Rating curves for Atlantic salmon and American shad spawning bio-period in Reach 1.

Reach 2

Rearing and Growth Bio-period

Brook trout, slimy sculpin, odonates, and GRAF had slightly decreasing habitat area availability with flow. Atlantic salmon and YOY had increasing habitat area with flow until around 0.25 cfsm where they remained stable. American eel had the greatest available habitat, starting with 100% at flows of 0.25 cfsm and decreasing to 93% at 1.0 cfsm. Atlantic salmon gained the most habitat area, increasing from 15% at 0.1 cfsm to 35% at 0.25 cfsm (Figure 20).

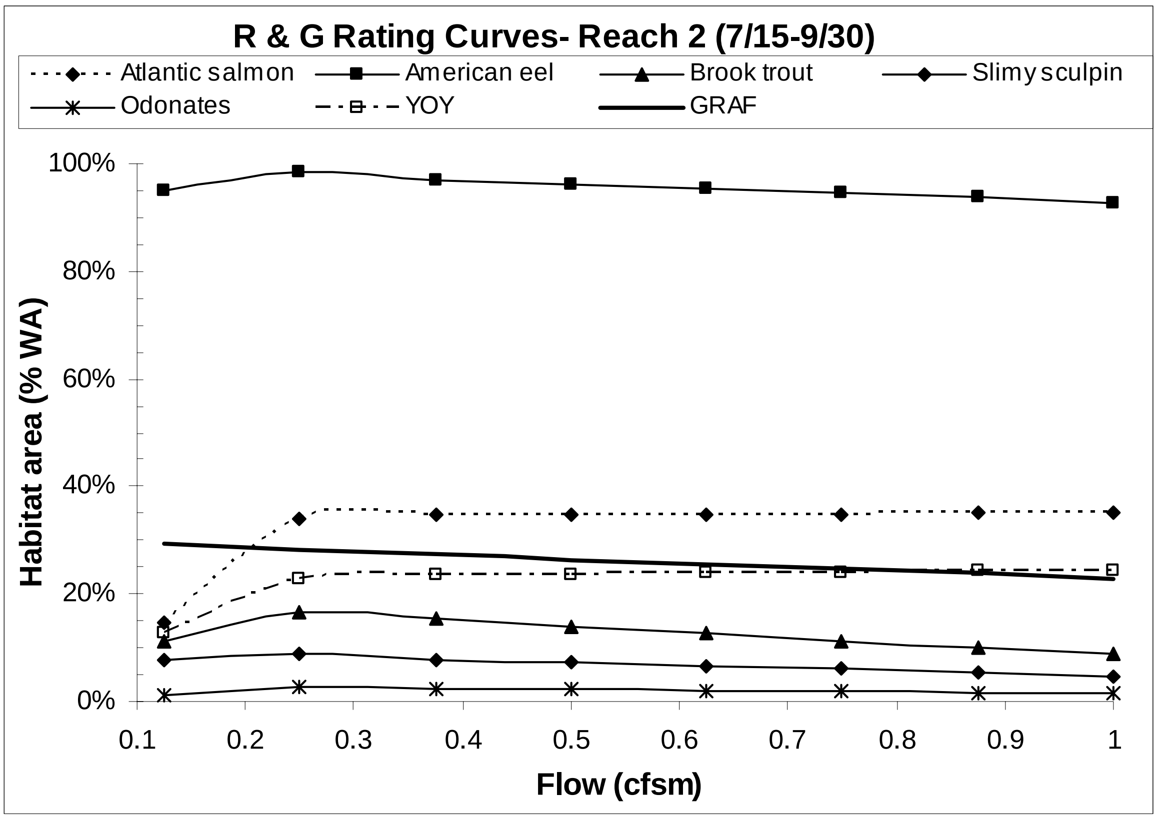


Figure 20. Habitat Rating curves for Reach 2 species during the R&G bio-period.

Spawning

Blacknose dace, common shiner, fallfish, longnose dace, white sucker, and GRAF all had increasing habitat area availability with flow until around 0.3 cfsm where they then decreased slightly with increasing flows. White sucker had the greatest available habitat area, reaching 90% at flows of 0.3 cfsm. White sucker also gained the most habitat area, increasing from 46% at 0.1 cfsm to 90% at 0.3 cfsm (Figure 21).

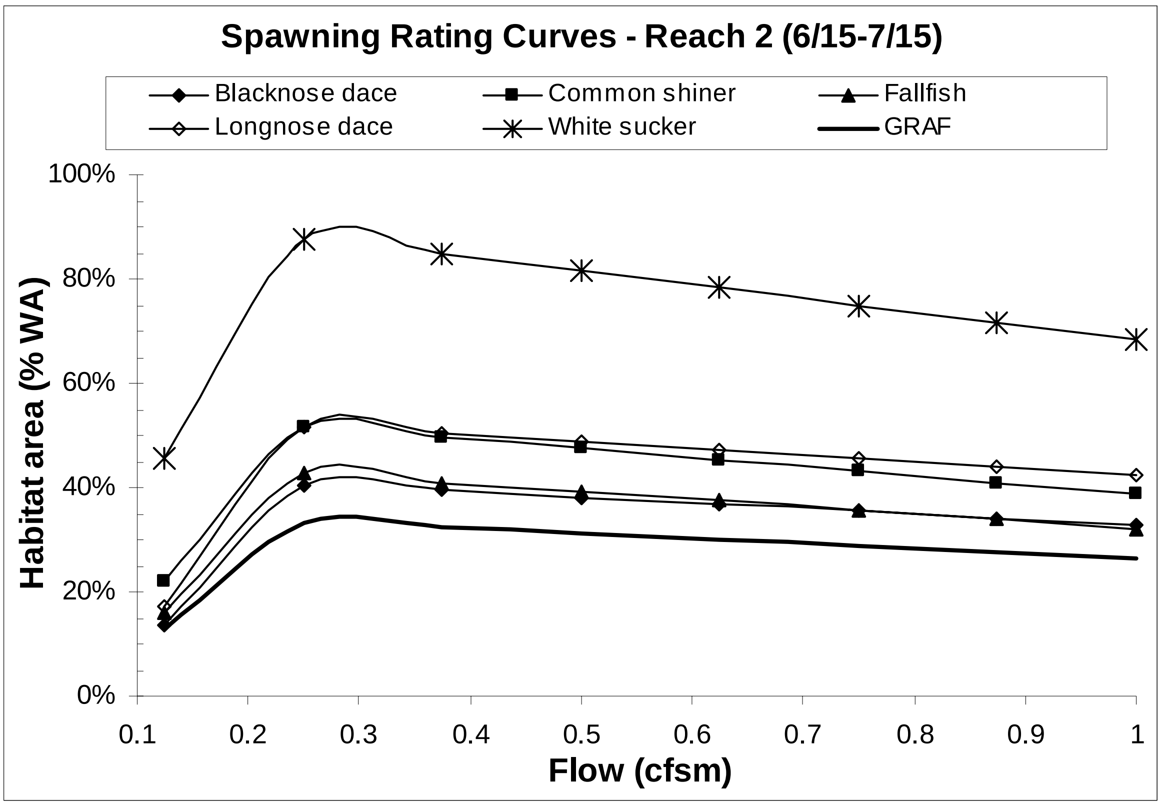


Figure 21. Habitat Rating curves for Reach 2 species during the Spawning bio-period.

Anadromous Spawning

Atlantic salmon habitat increased sharply from 20% available habitat at 0.1 cfsm to nearly 55% available at 0.3 cfsm, and then continued to increase gradually with increasing flows. American shad habitat area decreased slightly with increasing flow from 0.1 to 0.4 cfsm, at which point they each gained habitat area. American shad gained the most habitat area, increasing from 8% at 0.4 cfsm to 35% at 1.0 cfsm (Figure 22).

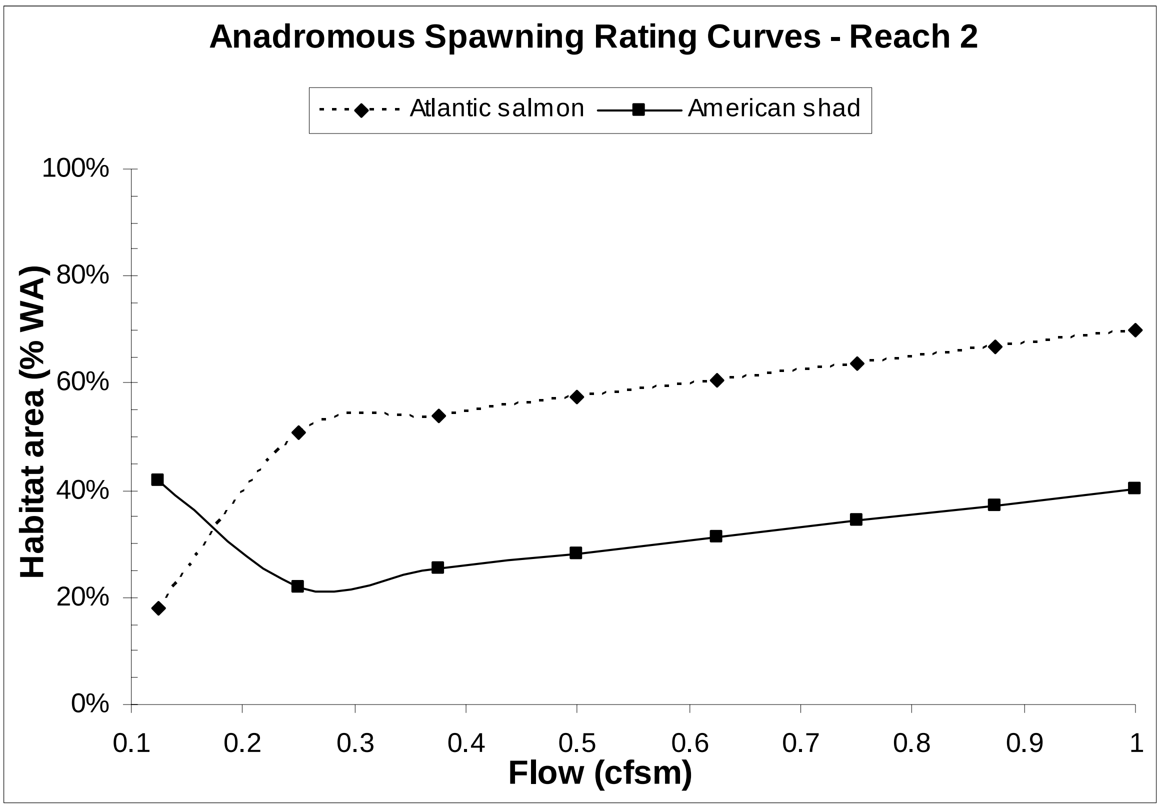


Figure 22. Habitat Rating curves for Atlantic salmon and American shad spawning bio-period in Reach 2.

Reach 3

Rearing and Growth Bio-period

Atlantic salmon, brook trout, odonates, and YOY each had increasing available habitat area with increasing flow. However, there was very little available habitat for odonates. American eel had the greatest available habitat, starting with 96% at flows of 0.1 cfsm, increasing to 100% at 0.3 cfsm and then decreasing to 92% at 1.0 cfsm. Slimy sculpin's habitat area decreased sharply from 26% at 0.1 cfsm to 10% at 0.25 cfsm and then rose gradually with increasing flow to 32% at 1.0cfsm. GRAF did not appear to be flow sensitive at this reach (Figure 23).

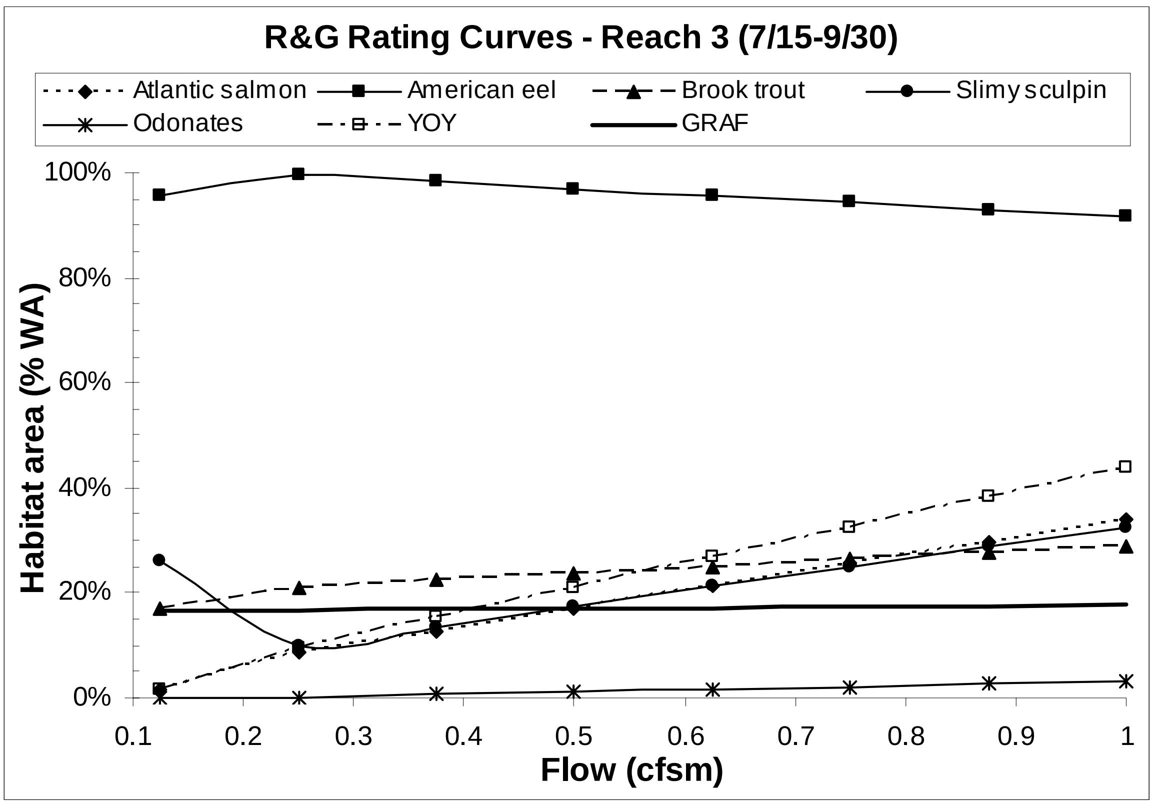


Figure 23. Habitat Rating curves for Reach 3 species during the R&G bio-period.

Spawning

Blacknose dace, common shiner, fallfish, longnose dace, white sucker, and GRAF all had increasing habitat area availability with flow. However, with the exception of white sucker, they all had relatively limited habitat area at all flows. White sucker gained the most habitat area, increasing from 23% at 0.1 cfsm to 35% at 1.0 cfsm (Figure 24).

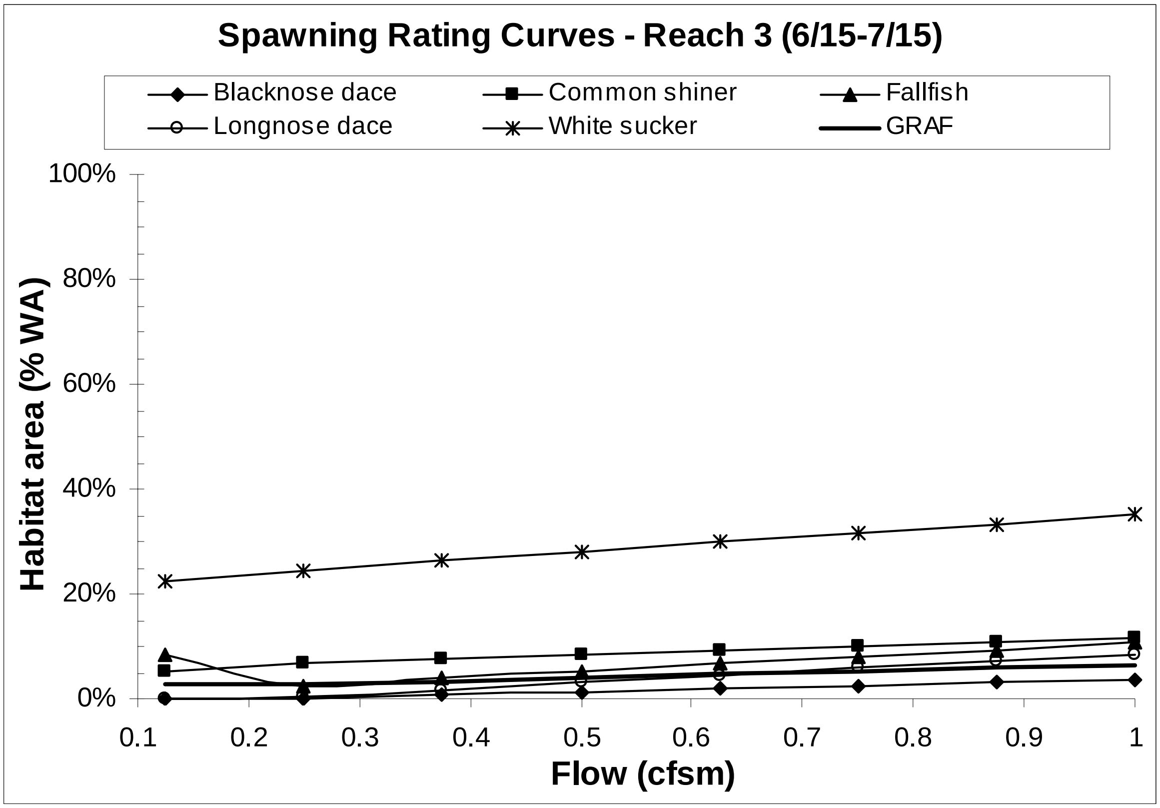


Figure 24. Habitat Rating curves for Reach 3 species during the Spawning bio-period.

Anadromous Spawning

Habitat area for American shad spawning increased from 25% at 0.1 cfsm to 55% at 0.25 cfsm before decreasing steadily to 17% at 1.0 cfsm. There was no available spawning habitat for Atlantic salmon (Figure 25).

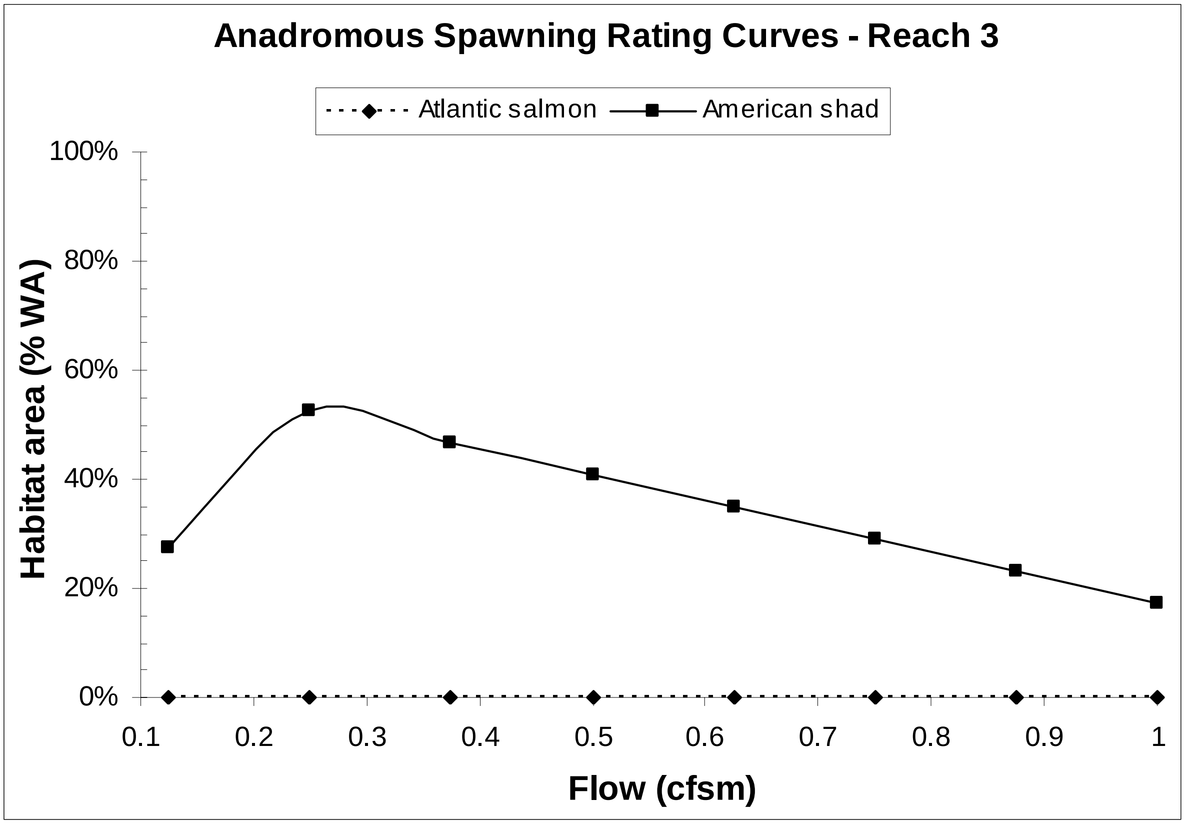


Figure 25. Habitat Rating curves for Atlantic salmon and American shad spawning bio-period in Reach 3.

Reach 4

Rearing and Growth Bio-period

Atlantic salmon, brook trout, odonates, and GRAF each had low percentages of habitat availability and showed very little change with increasing flows. There was very little habitat area for brook trout. American eel and YOY had nearly identical patterns. They both decreased from ~27% habitat area at 0.1 cfsm to ~18% at 0.25 cfsm then increased steadily with additional flow to 46% at 1.0 cfsm (Figure 26).

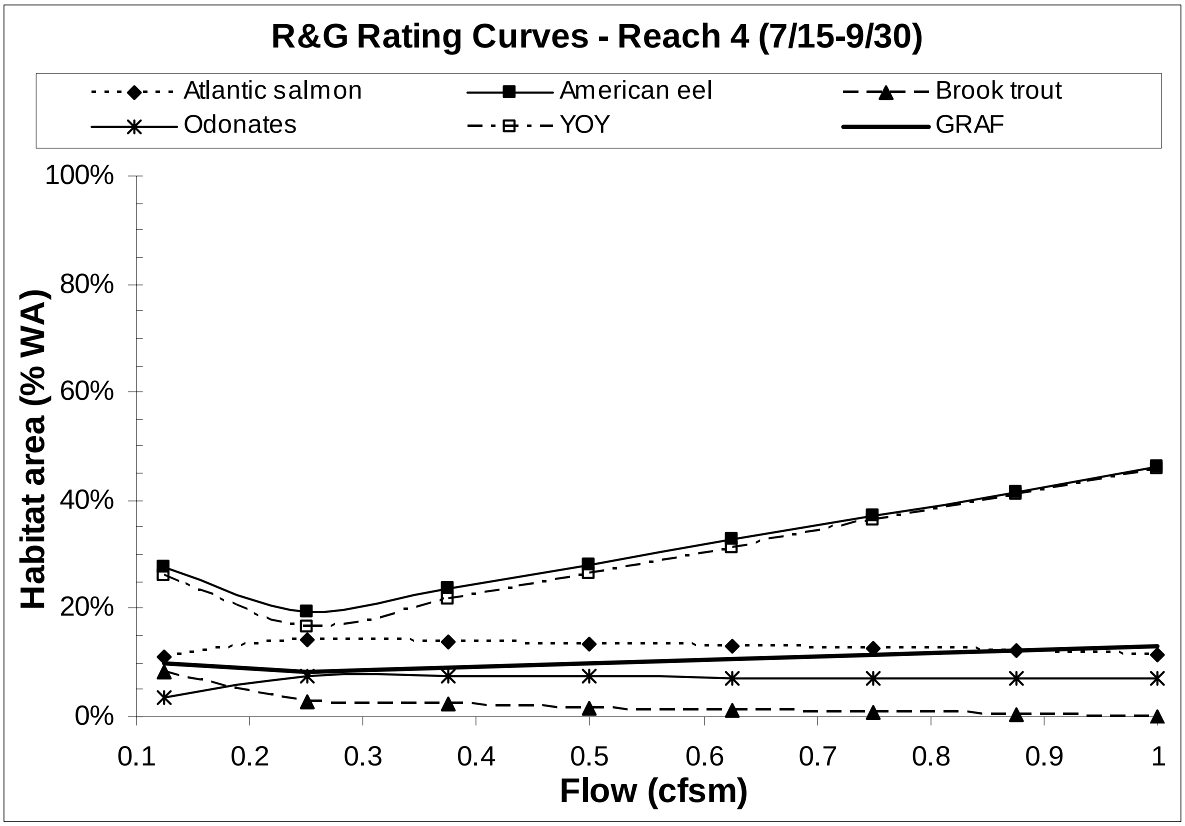


Figure 26. Habitat Rating curves for Reach 4 species during the R&G bio-period.

Spawning

Common shiner, fallfish, and white sucker all had maximum habitat area availability at 0.25 cfsm and decreased slowly with increasing flows. Blacknose dace and GRAF were not flow dependant at this reach. Longnose dace was the only species that had an increase in habitat area with additional flow, increasing from 7% at 0.25 cfsm to 19% at 1.0 cfsm (Figure 27).

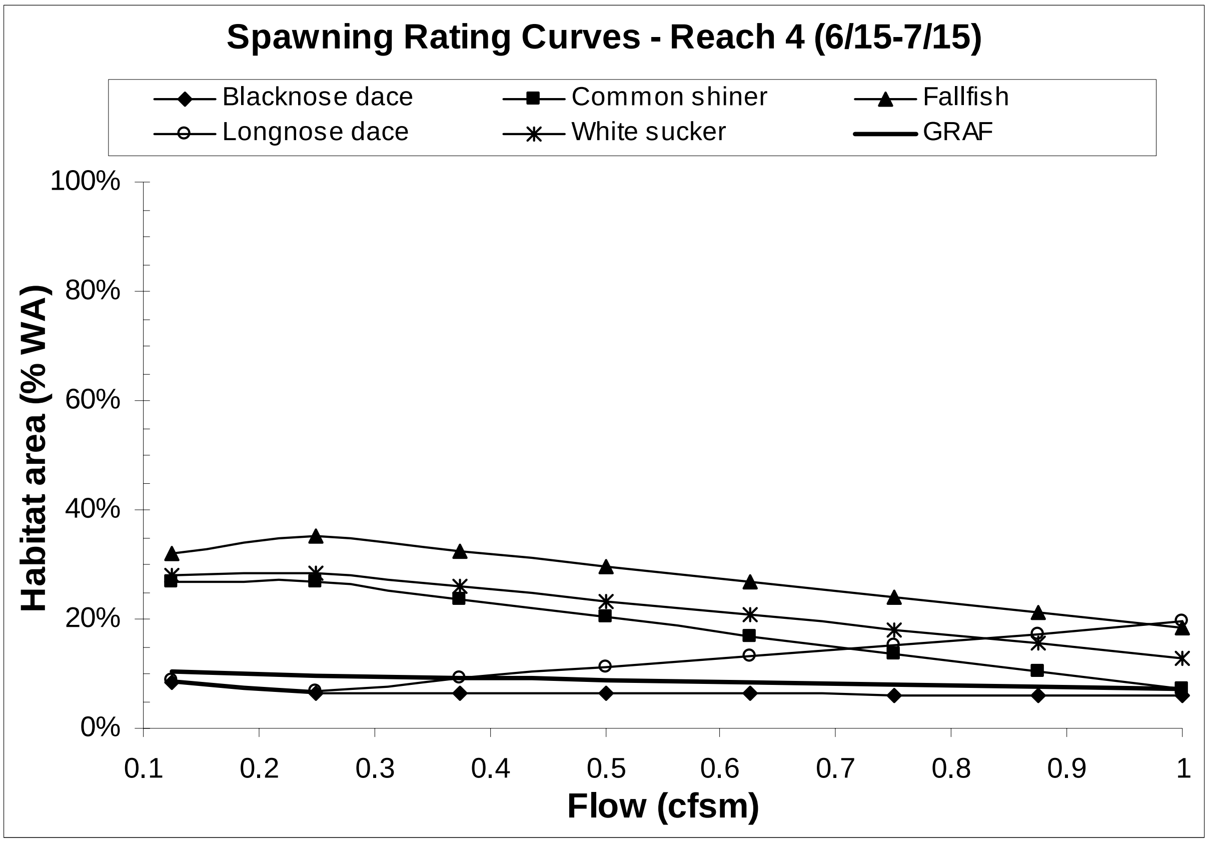


Figure 27. Habitat Rating curves for Reach 4 species during the Spawning bio-period.

Anadromous Spawning

Habitat area for American shad spawning decreased from 74% at 0.1 cfsm to 61% at 0.25 cfsm before increasing steadily to 82% at 1.0 cfsm. Habitat area for Atlantic salmon did not appear to be flow sensitive and ~15% was available at all flows (Figure 28).

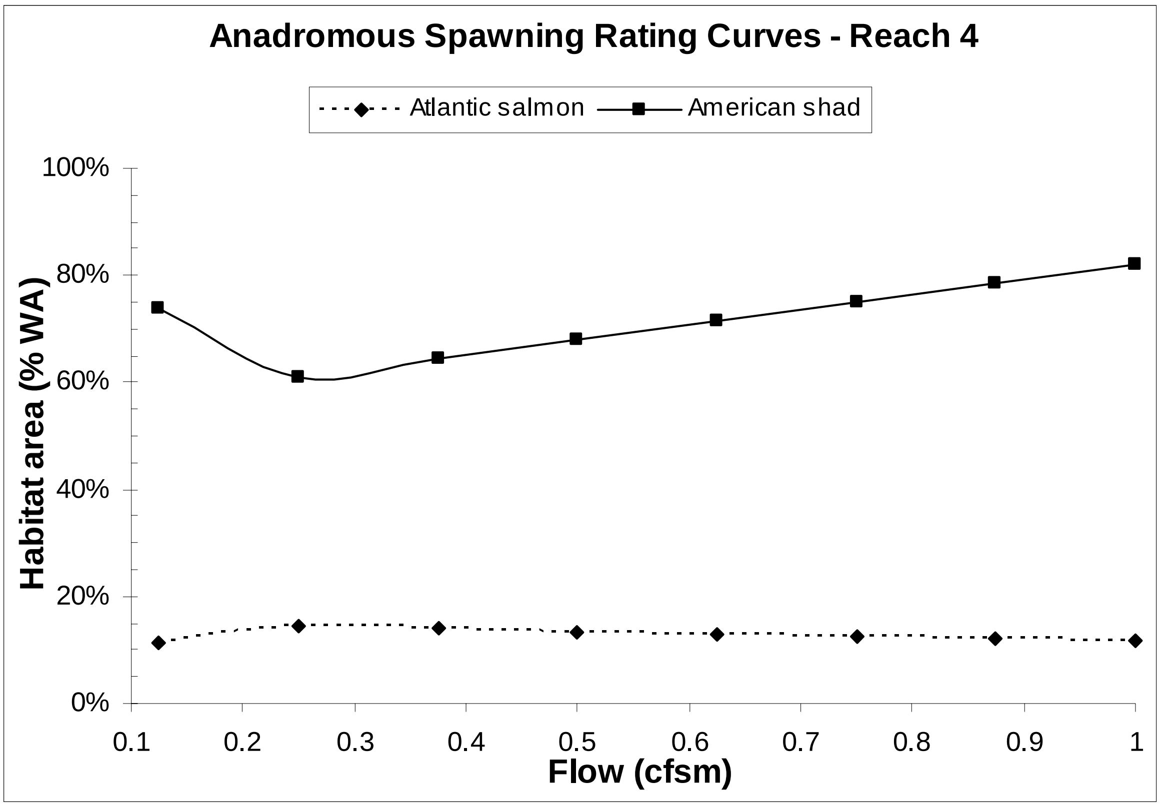


Figure 28. Habitat Rating curves for Atlantic salmon and American shad spawning bio-period in Reach 4.

Reach 5

Rearing and Growth Bio-period

Atlantic salmon, YOY, and GRAF were the only species that showed any increase with additional flow, although nearly stable. American eel, brook trout, and odonates all experienced decreasing habitat areas with increasing flows. American eel had the greatest available habitat, starting with 47% at flows of 0.1 cfsm and decreasing to 26% at 1.0 cfsm (Figure 29).

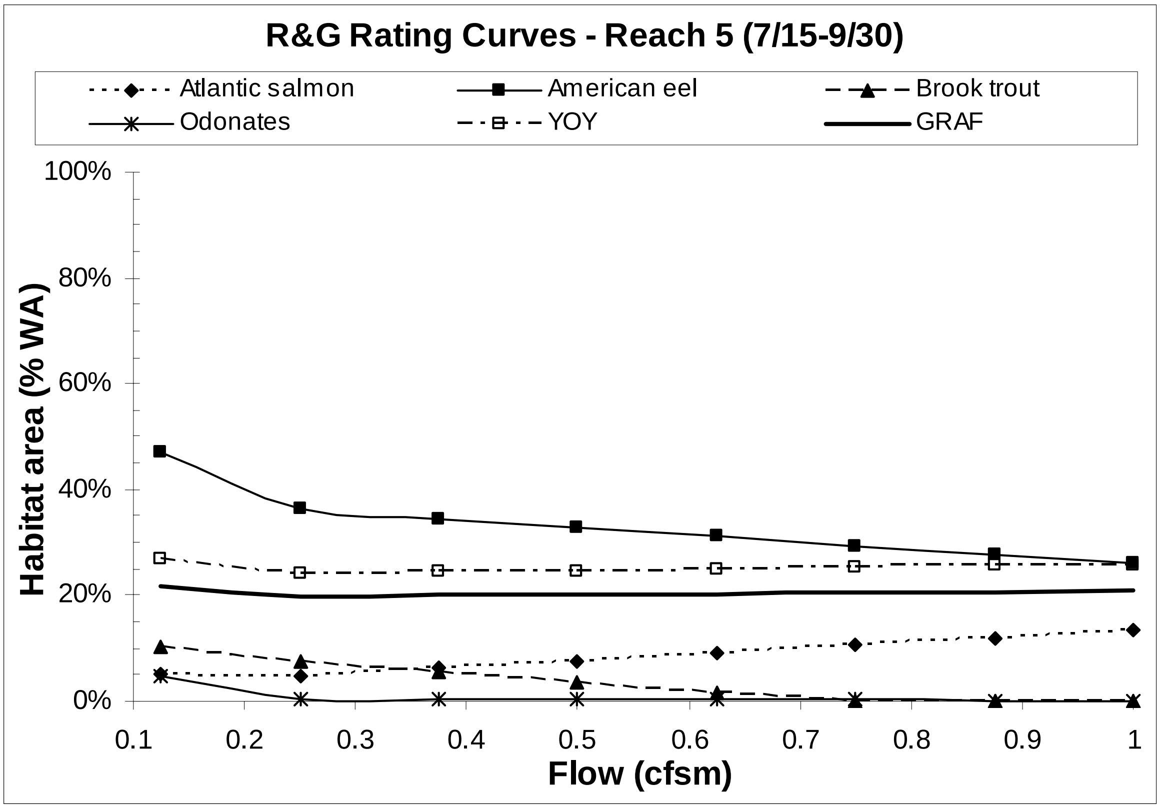


Figure 29. Habitat Rating curves for Reach 5 species during the R&G bio-period.

Spawning

Common shiner, fallfish, white sucker, and GRAF all had decreasing habitat areas with increasing flow. White sucker had greatest available habitat, remaining nearly stable at 35% throughout all flows. Habitat area for Blacknose dace decreased from 12% at 0.25 cfsm to 0% at 0.85 cfsm. Longnose dace was the only species with a slight increase in habitat availability with increasing flow (Figure 30).

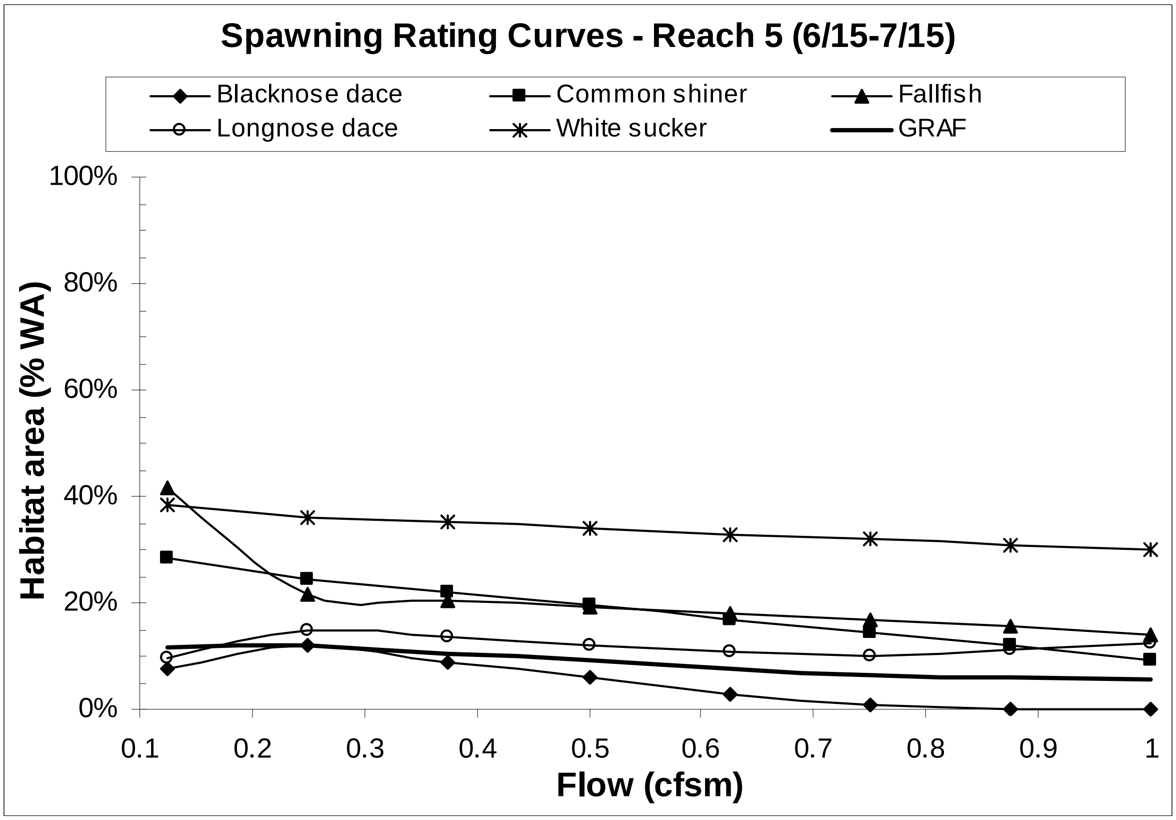


Figure 30. Habitat Rating curves for Reach 5 species during the Spawning bio-period.

Anadromous Spawning

Habitat area for American shad spawning decreased from 35% at 0.1 cfsm to 30% at 0.25 cfsm before increasing steadily to 79% at 1.0 cfsm. Habitat area for Atlantic salmon rose steadily from 5% at 0.1 cfsm to 13% at 1.0 cfsm (Figure 31).

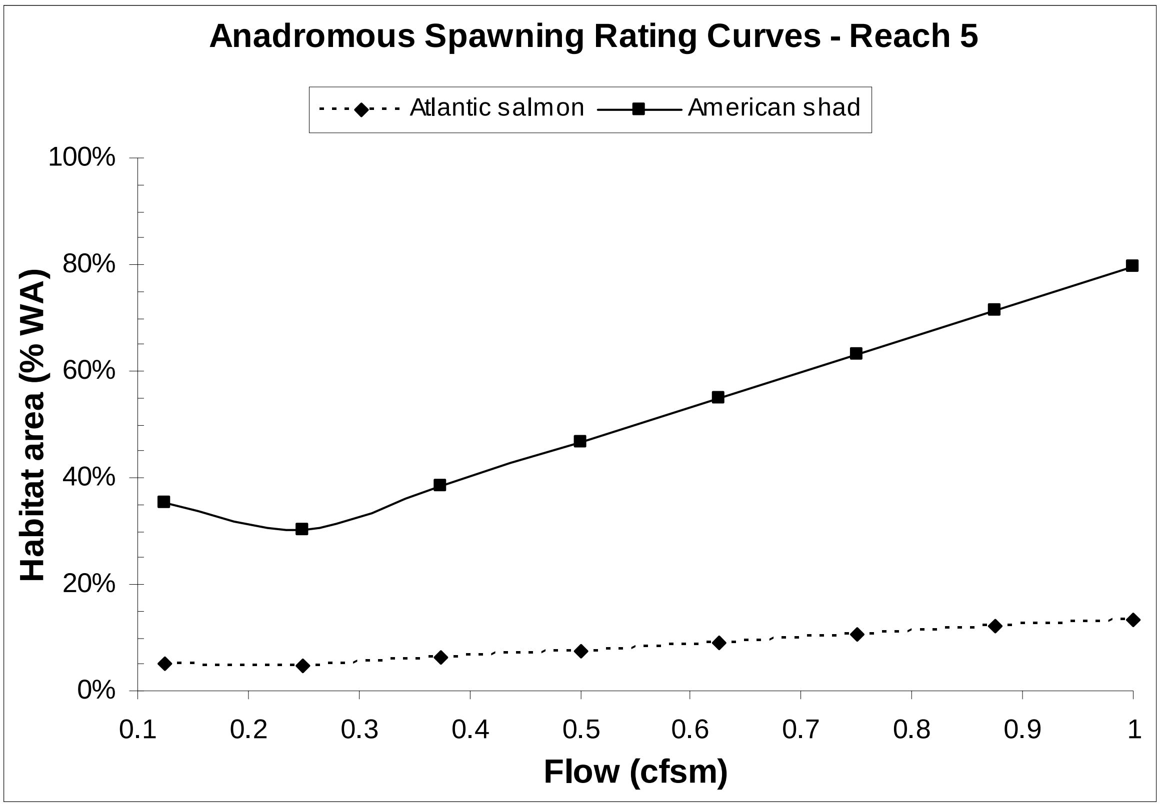


Figure 31. Habitat Rating curves for Atlantic salmon and American shad spawning bio-period in Reach 5.

Reach 6

Rearing and Growth Bio-period

Atlantic salmon, American eel, and brook trout all appeared to have very little habitat (<5%) at this reach, although they also appeared not to be flow dependent. Odonates and GRAF each had slightly decreasing habitat areas with increasing flows. Habitat availability areas for YOY increased slightly from 24% at 0.1 cfsm to 26% at 0.5 cfsm before decreasing rapidly to 0% at 1.0 cfsm. GRAF had the greatest available habitat at all flows, starting with 33% at flows of 0.1 cfsm and decreasing to 20% at 1.0 cfsm (Figure 32).

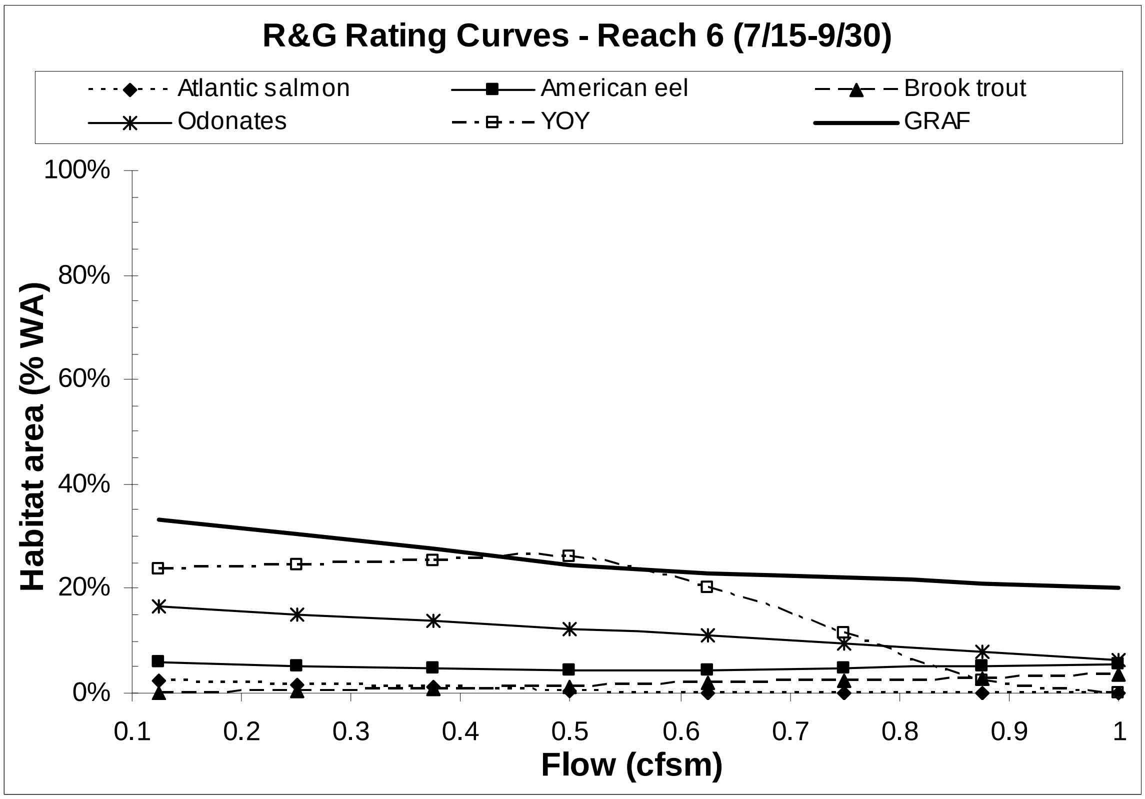


Figure 32. Habitat Rating curves for Reach 6 species during the R&G bio-period.

Spawning

Common shiner, fallfish, white sucker, and GRAF were all non-flow sensitive at this reach, although habitat area availability was low throughout all flows. Common shiner and fallfish had the greatest habitat availability with ~20% at all flows. Blacknose dace and longnose dace each lost habitat with increased flow, trending from 3% at 0.1 cfsm to 0% at 0.85 cfsm and 11% at 0.1 cfsm to 0% at 0.75 cfsm respectively (Figure 33).

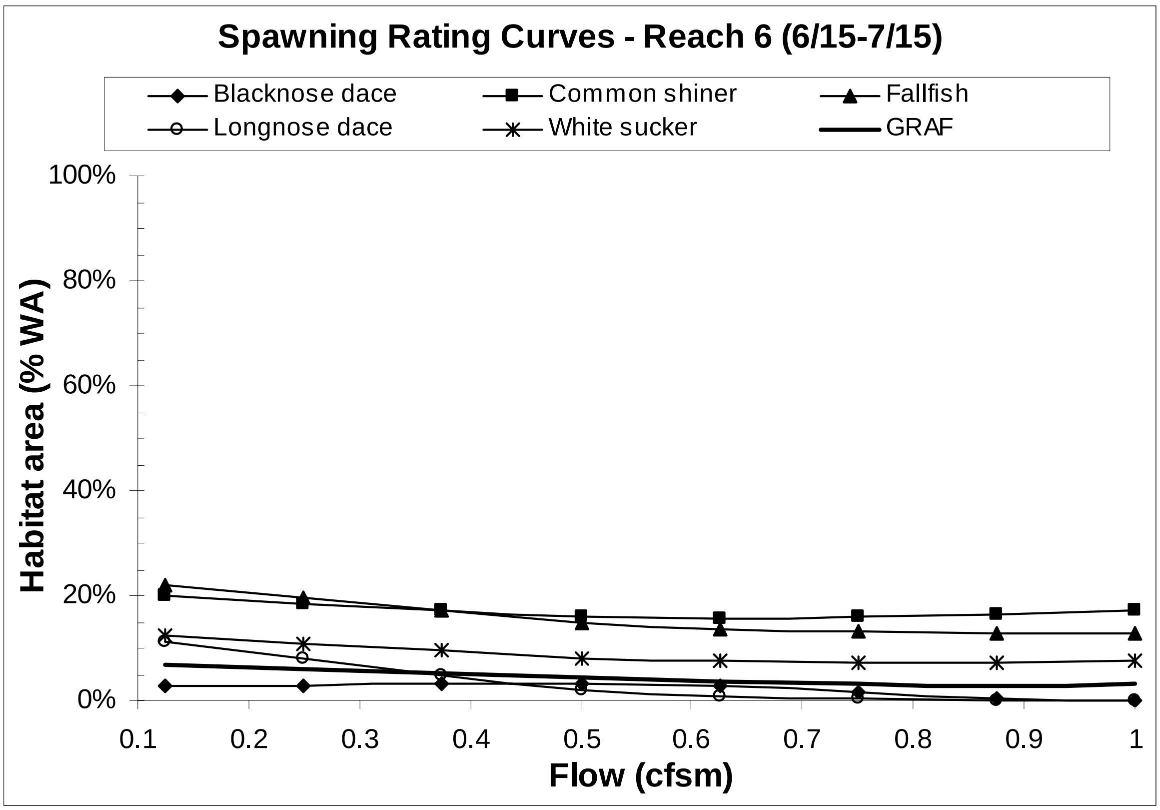


Figure 33. Habitat Rating curves for Reach 6 species during the Spawning bio-period.

Anadromous Spawning

Habitat area for American shad spawning increased from 45% at 0.1 cfsm to 64% at 0.5 cfsm before increasing steadily to 59% at 1.0 cfsm. Habitat area for Atlantic salmon decreased slightly from 3% at 0.1 cfsm to 0% at 0.5 cfsm (Figure 34).

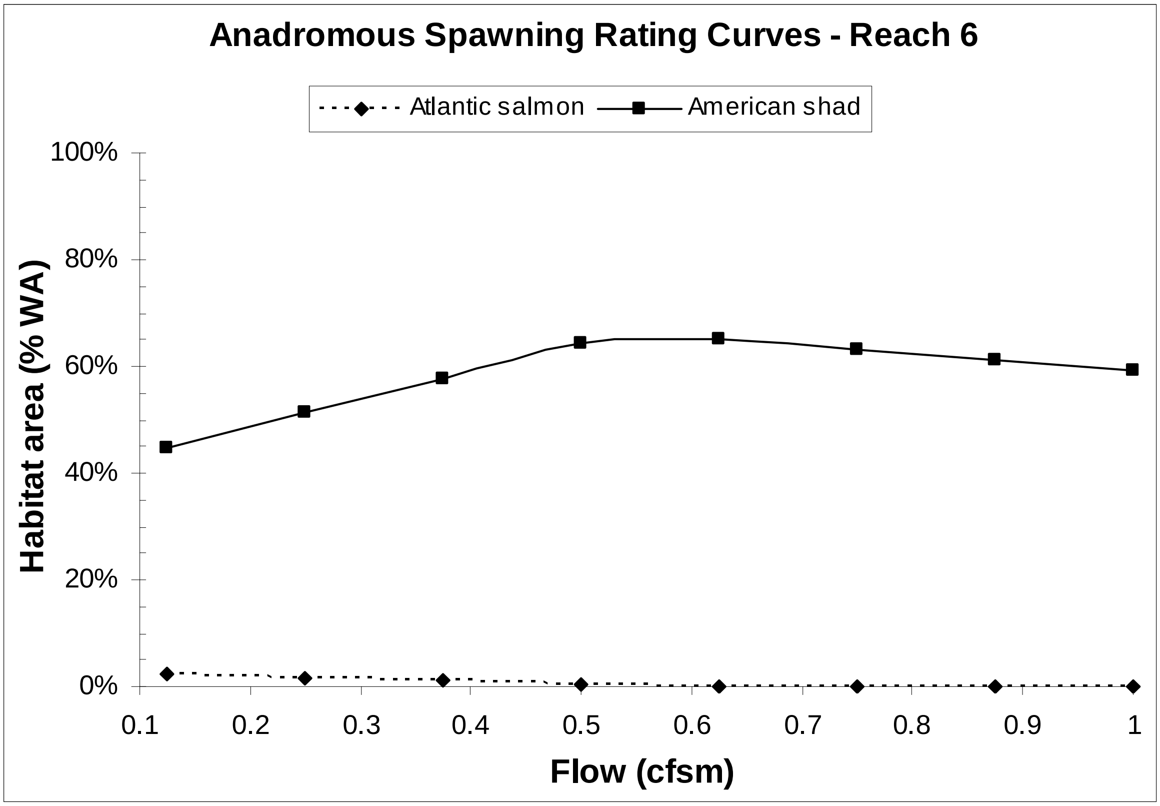


Figure 34. Habitat Rating curves for Atlantic salmon and American shad spawning bio-period in Reach 6.

Reach 7

Rearing and Growth Bio-period

American Eel and brook trout each gained habitat area with increasing flow from ~5% at 0.1 cfsm to ~15% at 1.0 cfsm. There was essentially no Atlantic salmon habitat available in this reach. GRAF species habitat area decreased from 22% at 0.1 cfsm to 14% at 0.5 cfsm and then remained stable with increasing flow. YOY habitat was largely non-flow dependant remaining at around 24%, with the exception of a slight rise in habitat area to 32% at 0.25 cfsm. Habitat area for odonates increased from 40% at 0.1 cfsm to 48% at 0.25 cfsm before decreasing steadily to 13% at 0.6 cfsm and then remaining stable (Figure 35).

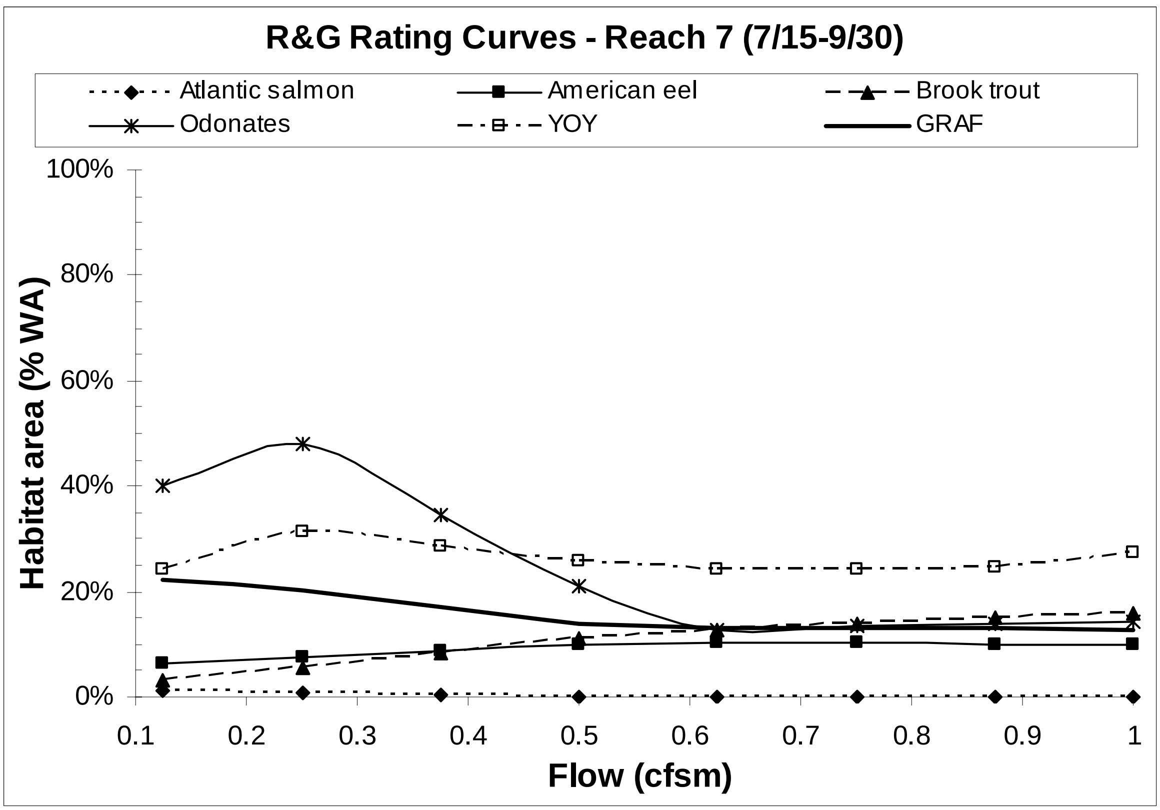


Figure 35. Habitat Rating curves for Reach 7 species during the R&G bio-period.

Spawning

Habitat areas for the species blacknose dace, common shiner, fallfish, longnose dace, white sucker, and GRAF all decreased with increasing flow from 0.1 cfsm to 0.5 cfsm and then remained stable with additional flow. All species had less than 20% suitable spawning area (Figure 36).

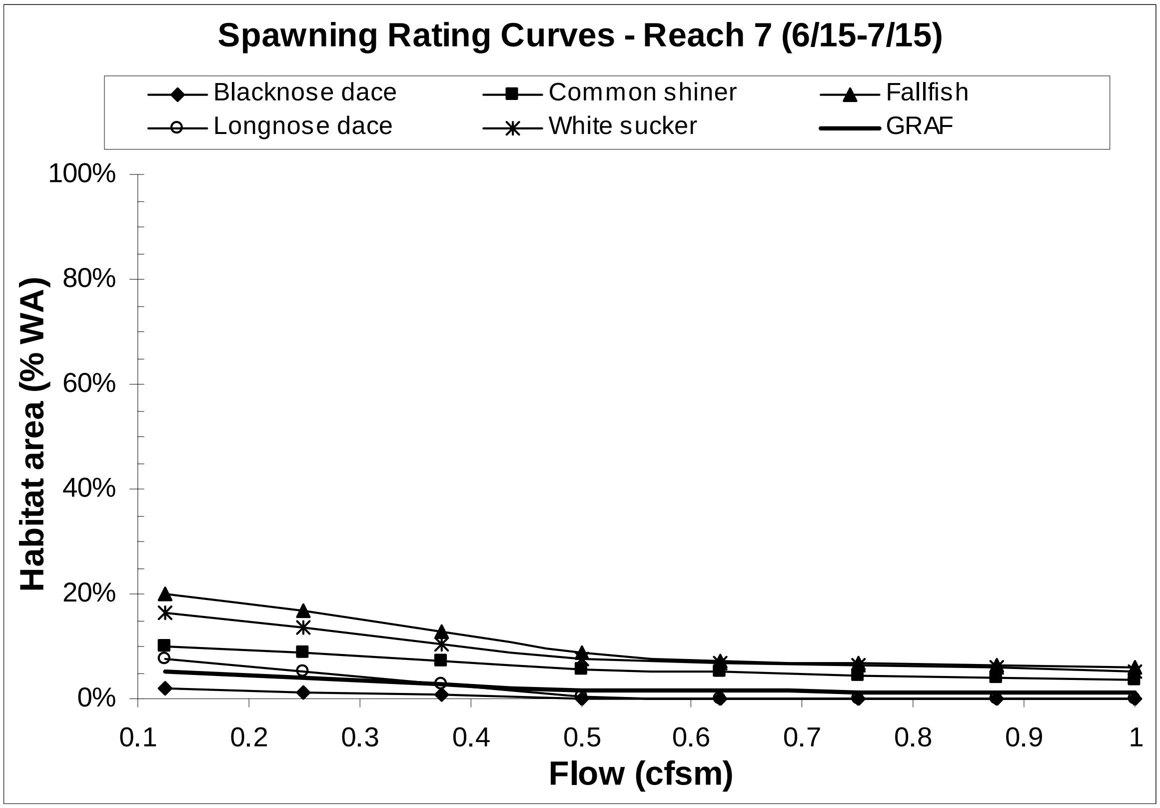


Figure 36. Habitat Rating curves for Reach 7 species during the Spawning bio-period.

Anadromous Spawning

Habitat area for American shad spawning increased from 15% at 0.1 cfsm to 19% at 0.25 cfsm before declining to 7% at 0.6 cfsm and then remaining stable with additional flow. There was no available salmon spawning habitat in this reach (Figure 37).

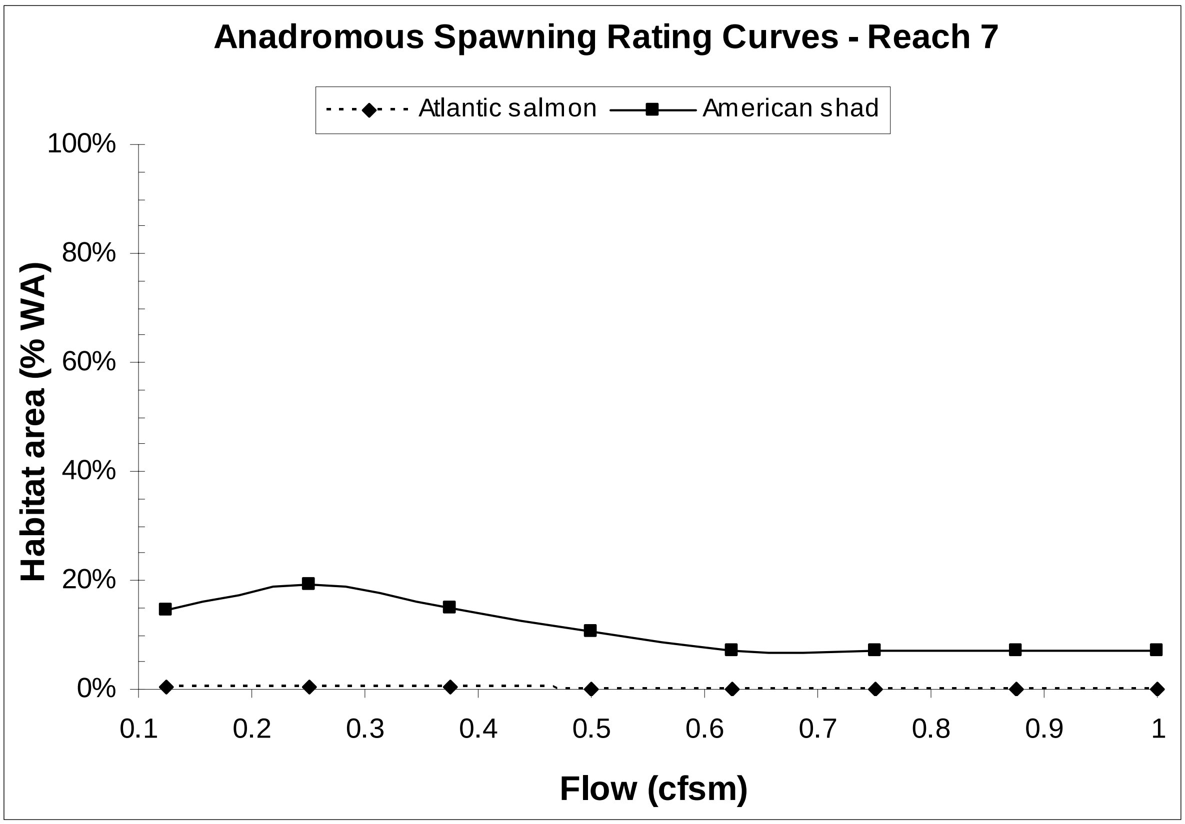


Figure 37. Habitat Rating curves for Atlantic salmon and American shad spawning bio-period in Reach 7.

River Restoration Simulation

Results of assessment methods were integrated into a GIS model that can be used to test management scenarios that would enhance habitat in addition to PISF. Based on known habitat needs of aquatic species geomorphologic setting, and historical information, river channel improvements due to flow or other habitat manipulations (e.g. bank stabilization, or connecting side arms) can be simulated by changing habitat attributes recorded during the field surveys. The potential of these measures can be analyzed by simulation of the gain in fish habitat.

The model modifications investigated a minimally invasive and low-cost restoration option for the Souhegan River. After completing the mapping surveys, it was clear that there was an absence of woody debris in the river. Simulation efforts were therefore geared toward restoration of river canopy cover and the implied addition of woody debris in the attributes tables. It is acknowledged that the addition of woody debris could have an effect on the distribution and size of hydromorphologic units and other intrinsic attributes, but the prediction of these changes is limited. The model rating curves are therefore a look at the instantaneous available habitat changes. Since these factors would affect only the Rearing and Growth habitat model, the analysis was conducted for this season only. A site-by-site listing of all attribute and HMU modifications follows below.

Site 1:

- Woody debris maximized in all HMUs.
- Canopy cover set to present if not already there.
- Information from site 1 used to simulate removal of the Greenville, NH impoundment.

Site 2

- Woody debris increased by a category. If previously absent, then set to present and if previously present, then set to abundant.
- Undercut bank presence added to cut banks in upper sections.
- Canopy cover increased in upper section where site is exposed by road cut.

Site 3

- This site was removed from the restoration simulation model because of possible river modifications related to the large highway overpass.
- Information from site 4 (~500 m downstream) used to represent this area.

Site 4

- Woody debris increased by a category. If previously absent, then set to present and if previously present, then set to abundant.

Site 5

- Woody debris increased by a category. If previously absent, then set to present and if previously present, then set to abundant.
- Canopy cover set to present if not already there.
- Information from site 5 used to simulate the removal of the two Wilton, NH impoundments.

Site 6

- Woody debris increased by a category. If previously absent, then set to present and if previously present, then set to abundant.
- Canopy cover set to present if not already there.
- Backwaters (HMU# 60216, 60526, 60128) modified and reconnected to form a sidearm.
- Backwaters (HMU# 60525, 60125, 60516) enlarged.
- Backwater (HMU# 61019) modified and reconnected to form a sidearm.

Site 7

- Woody debris set to present if not already there.
- A backwater (HMU# 70525) created in a former oxbow using data from HMU# 70510.
- A sidearm (HMU# 70526) created in a floodplain scar using data from HMU#70514.
- A backwater (HMU# 71036) created in a former oxbow using data from HMU# 71017.
- A sidearm (HMU# 71037) created in a floodplain scar using data from HMU#71023.
- Information from site 7 used to simulate the removal of the two Milford, NH impoundments.

Site 8

- Woody debris set to present if not already there.
- Canopy cover increased by a category. If previously absent, then set to present and if previously present, then set to abundant.

Site 9

- Woody debris set to abundant.
- Canopy cover set to present if not already there.

Site 10

- Woody debris increased by a category. If previously absent, then set to present and if previously present, then set to abundant.
- Canopy cover increased by a category. If previously absent, then set to present and if previously present, then set to abundant.

Site 11

- Removed from the simulation, which ended at the USGS gauging site just above Wildcat Falls (see below).

River Simulation Results

The following are descriptions of observed changes in suitable habitat areas between the original MesoHABSIM model and the simulation of river restoration improvements.

Reach 1

Available habitat area for American eel, brook trout, YOY, and GRAF increased at all flows with the addition of woody debris and canopy shading. Atlantic salmon habitat remained nearly identical to pre-modified conditions. Slimy sculpin gained habitat at low flows, but experienced a net loss at high flows. Overall slimy sculpin's available habitat remained more stable with at least 25% at all flows. There was still no available habitat for odonates in the restoration model. Modification had the greatest positive impact on brook trout, YOY, and GRAF in this reach (Figure 38).

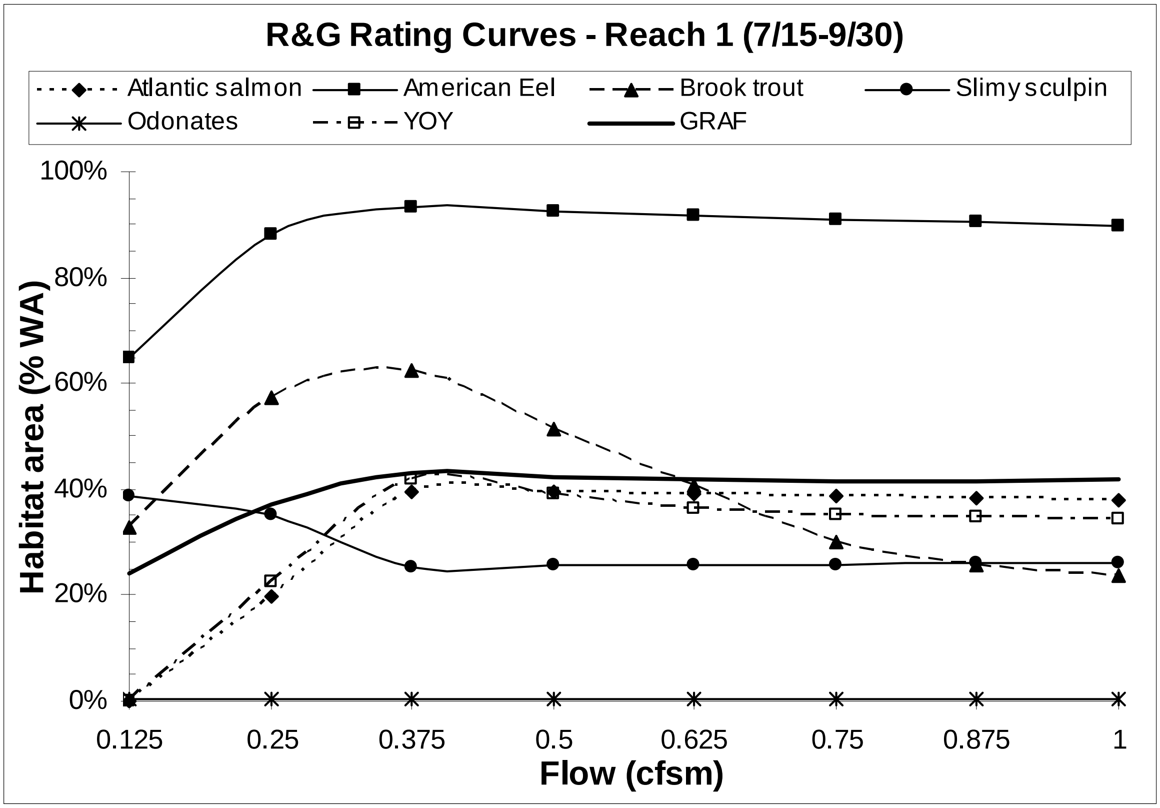


Figure 38. Habitat Rating curves for Reach 1 river restoration simulation species during the R&G bio-period.

Reach 2

Available habitat area for American eel, odonates, slimy sculpin, GRAF, and Atlantic salmon did not change significantly between the two models. Habitat availability for brook trout increased at all flows, particularly between 0.2 and 0.6 cfsm. Modification had the greatest positive impact on YOY habitat area in this reach, remaining above 60% in flows above 0.2 cfsm (Figure 39).

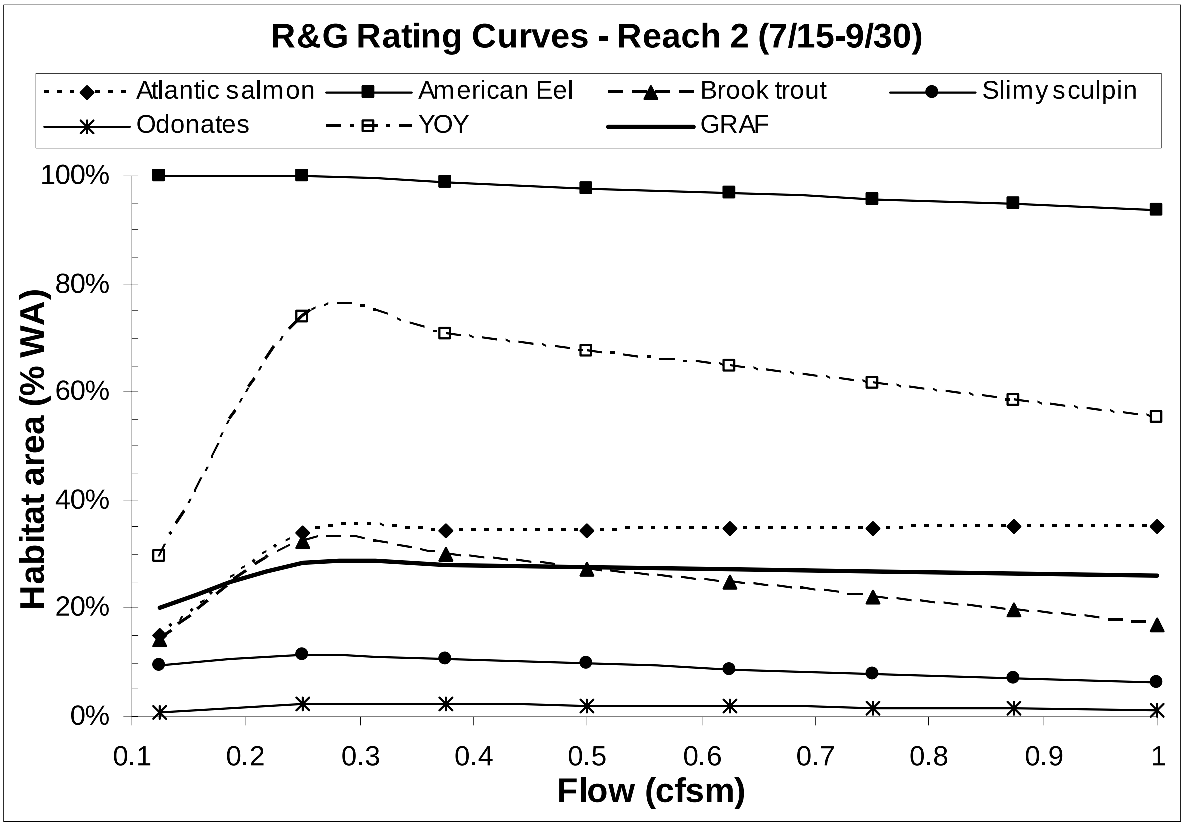


Figure 39. Habitat Rating curves for Reach 2 river restoration simulation species during the R&G bio-period.

Reach 3

Available habitat area for Atlantic salmon, American eel, odonates, and GRAF did not change significantly between the two models. Habitat availability for brook trout increased dramatically, surpassing 55% in all flows. YOY habitat area increased slightly in a linear fashion from 0% at 0.1 cfsm to 57% at 1.0 cfsm. Modification had the greatest positive impact on brook trout and slimy sculpin in this reach (Figure 40).

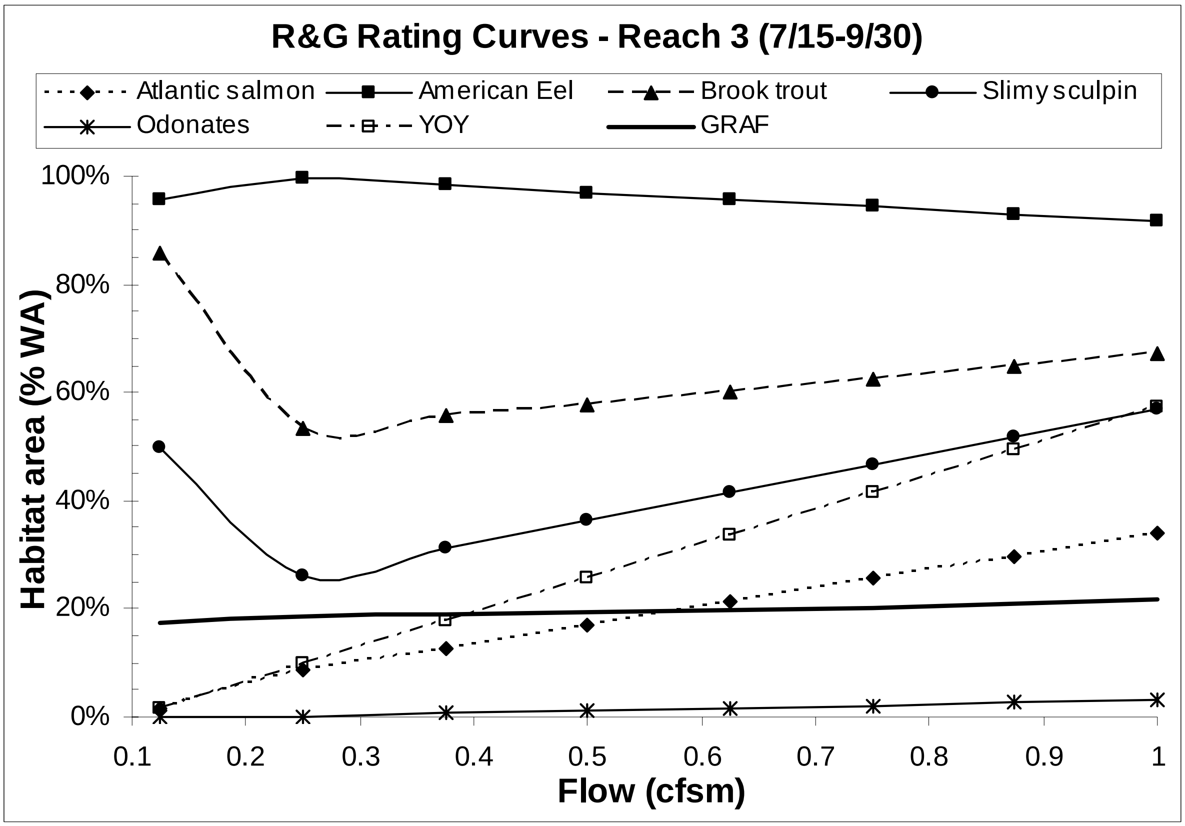


Figure 40. Habitat Rating curves for Reach 3 river restoration simulation species during the R&G bio-period.

Reach 4

YOY and GRAF habitat area increased significantly in our restoration simulation model at all flow conditions, generally remaining above 50%. Odonate habitat area, in the restoration model, had significant gains with flows in excess of 0.25 cfsm. Available habitat area for Atlantic salmon and American eel did not change significantly between the two models. Brook trout gained some habitat area at higher flows, but generally remained at low levels. Modification had the greatest positive impact on YOY, GRAF, and odonates in this reach (Figure 41).

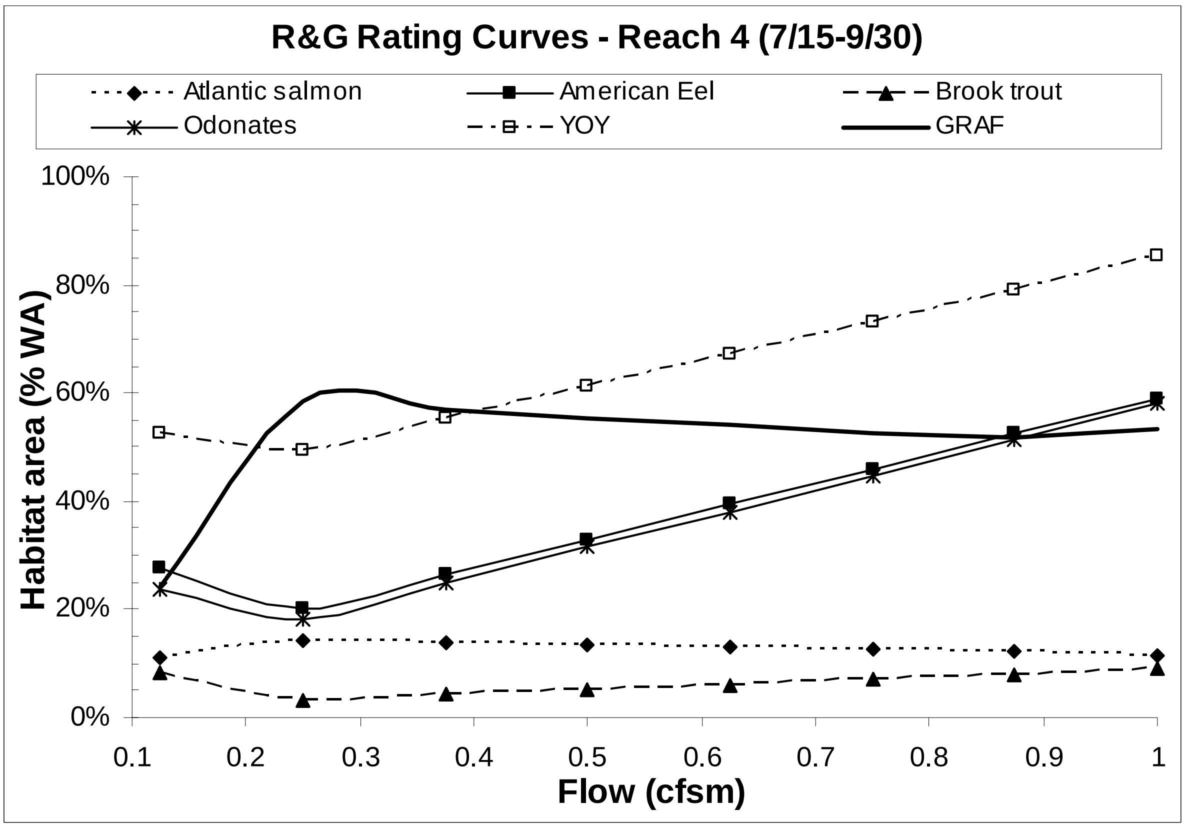


Figure 41. Habitat Rating curves for Reach 4 river restoration simulation species during the R&G bio-period.

Reach 5

YOY habitat area increased significantly in our restoration simulation model at flows above 0.25 cfsm. Available habitat area for Atlantic salmon, American eel, GRAF, and odonates did not change significantly between the two models. Brook trout gained some habitat area at higher flows, but generally remained at low levels. River modification showed little increased habitat in this reach, with the exception of YOY at flows above 0.3 cfsm (Figure 42).

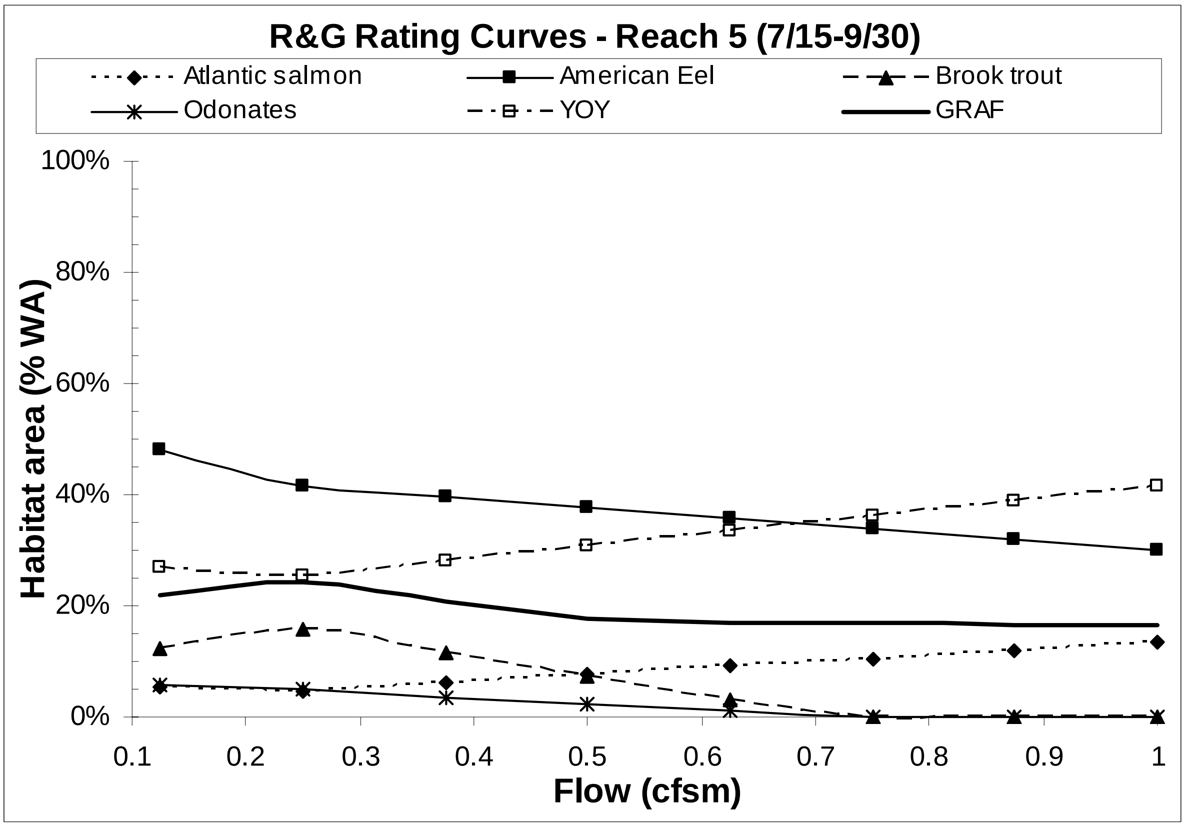


Figure 42. Habitat Rating curves for Reach 5 river restoration simulation species during the R&G bio-period.

Reach 6

Habitat area for American eel, Atlantic salmon, YOY, and GRAF did not change significantly between the two models. Odonate habitat area increased slightly at all flows with the greatest increase at flows over 0.5 cfsm. Brook trout habitat area remained mostly unchanged until at flows greater than 0.5 cfsm where habitat area began to increase. River modification showed little increased habitat in this reach, with the exception of odonates and brook trout at flows above 0.3 cfsm (Figure 43).

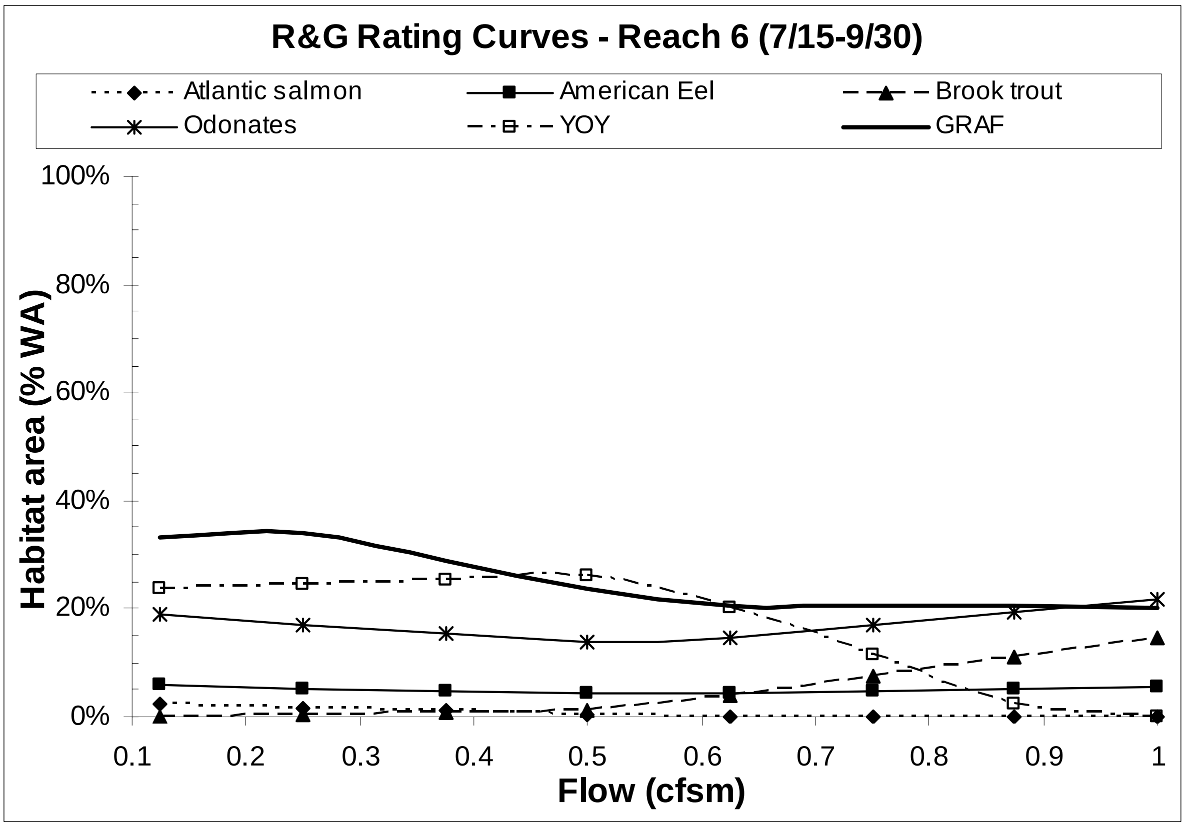


Figure 43. Habitat Rating curves for Reach 6 river restoration simulation species during the R&G bio-period.

Reach 7

Habitat area for Atlantic salmon, American eel, brook trout, and YOY did not change significantly between the two models. There was a slight overall decrease in habitat area for GRAF species at all flows. Habitat area for odonates increased significantly at flows between 0.1 and 0.5 cfsm, but were slightly lower at flows over 0.5 cfsm. River modification showed little increased habitat in this reach, with the exception of odonates at flows between 0.1 and 0.5 cfsm (Figure 44).

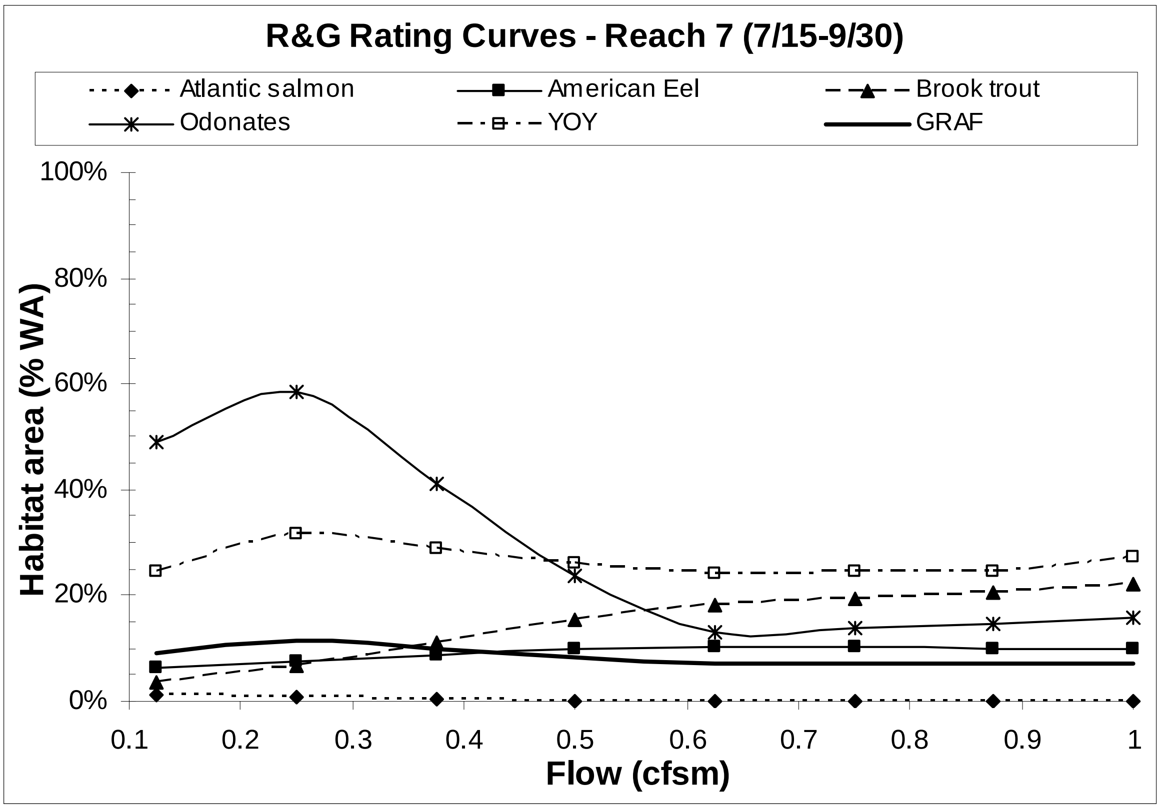


Figure 44. Habitat Rating curves for Reach 7 river restoration simulation species during the R&G bio-period.

Habitat Time Series Analysis

The purpose of this task was to develop habitat augmentation rules to avoid or mitigate both pulse and press disturbances (Niemi et al. 1990). The key criteria for these rules were developed by the determination of habitat stressor thresholds (HST) from their frequency of occurrence. Intra-annual rules should specify the magnitude of extreme habitat that should always be exceeded, as well as the magnitude and the duration of low-habitat events that are common in an average year. Inter-annual rules should define how frequently uncommonly low and long events could occur.

We distinguished two duration types for rare events: persistent lows that can happen two or three years in a row (equivalent to a press disturbance); and catastrophic events that occur on the decadal scale (pulse stressors). All of these rules are organized by annual bio-periods.

To identify HST, habitat time series were developed and the habitat duration curves analyzed, then uniform continuous under-threshold habitat-duration curves (UCUT-curves) modified from Capra et al. (1995) (see Appendix 12). The curves evaluate durations and frequency of continuous events with habitat lower than a specified threshold. With the help of this technique, three habitat quantities that correspond with different types of thresholds in the bio-periods were identified. From inflection points on duration curves and position of UCUTs *rare, critical, and typical* habitat levels were designated.

For each of the thresholds, the longest typical or allowable durations were identified, which demarcated the beginning of persistent low habitat. The shortest of uniquely long durations appearing on the decadal scale are defined as catastrophic durations and are accompanied by their frequency of occurrence.

To develop habitat time series, the habitat rating curves described in the last paragraph are applied to simulated flow time series as developed for specific reaches. Table 16 documents which gages were used to represent flow in a reach and Figure 6 shows their locations. Due to the limited number of flow observation at some gages (caused by floods that damaged most of the gages), the flow readings of neighboring gages were lumped in pairs to provide more robust representation of flows in a reach. Because not all species or life stages are sensitive to flow changes in the habitat use, only rating curves that indicate such habitat are selected for development of habitat time series. During the R&G and resident-species spawning seasons the preference was to choose GRAF as indicator. Only if the GRAF rating curve did not display any changes with flow or if other species were much more flow dependent were rating curves for individual species or the YOY life stage used. During the R&G bio-period the Habitat Duration Curve (HDC) and UCUT curves were computed for selected indicator species in every reach using a time series from neighboring flow gauges.

Because the spawning models were less precise than those for the R&G season and during spawning bio-periods flows are usually higher than in summer, to establish PISF criteria for these times the HDC and UCUTs were computed for the most flow-sensitive reach in a segment. For seasons or reaches where habitat information was insufficient flow based time series analysis were applied.

PISF recommendations were developed for each segment by taking the highest of the habitat needs and the longest allowable and catastrophic durations identified in investigated reaches. For each habitat level flows at the bottom of each Segment necessary to achieve this level were computed. To represent the Upper Souhegan, the location equivalent to gage in Section 25 with a drainage area of 102.3 mi^2 was selected, and for the Lower Souhegan the location of the USGS gage in Merrimack, NH with a drainage area of 171 mi^2 was selected.

R&G Bio-Period

Table 16. Species and life stages selected as habitat indicators in each specific reach. See Appendix 12 for the curves and the PISF criteria established for each reach from the analysis of HDC and UCUTs.

Indicator	**GRAF**	**ATS**	**YOY**	**YOY**	**ATS**	**GRAF**	**YOY**	**Recommended flows**	
Gauge (SR#)	6-12	16-18	25	31-34	31-34	50-56	50-56	25	USGS
Watershed area (mi^2)	33.9	64.6	102.3	139	139	159	159	102.3	171
Location	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Reach 6**	**Reach 7**	**Upper**	**Lower**
Common habitat (% WA)	**13**	**12**	**7**	**30**	**5.5**	**34**	**23**		
Allowable duration under (days)	30	28	30	28	30	20	23	30	20
Catastrophic duration (days)	42	42	45	42	42	40	40	42	40
Corresponding flow present (cfsm)	0.3	0.12	0.21	0.6	0.31	0.12	0.12	0.3	0.6
Common flow (cfs)	10	8	21	83	43	19	19	31	103
Habitat when restored (% WA)	43	20	7	55	6	33	29		
Critical habitat (% WA)	**10**	**4**	**1.5**	**22.5**	**5.2**	**27**	**19**		
Allowable duration under (days)	15	18	17	10	17	15	15	15	15
Catastrophic duration (days)	35	35	40	15	20	27	27	35	20
Corresponding flow present (cfsm)	0.16	0.04	0.13	0.11	0.15	0.1	0.08	0.16	0.15
Critical flow (cfs)	5	3	13	15	21	16	13	16	26
Habitat when restored (% WA)	26	19	2	52	5	27	22		
Rare habitat (% WA)	**7**	**2**	**1**	**20**	**5**	**22**	**18**		
Allowable duration under (days)	5	10	10	5	5	7	5	5	5
Catastrophic duration (days)	32	15	35	10	10	15	10	30	10
Corresponding flow (cfsm)	0.10	0.03	0.10	0.10	0.11	0.08	0.05	0.1	0.1
Rare flow (cfs)	3	1	10	14	15	13	8	10	17
Habitat when restored (% WA)	22	14	1	52	5	22	19		

In Reach 1 commonly GRAF habitat stays under 13% WA for no longer than 30 days, and 42 days represent catastrophic duration. At present conditions this habitat level corresponds with flows of 0.3 cfsm (10 cfs). If habitat was improved by restoration the same flows would more than double the GRAF habitat to 43% WA. Critical events begin if habitat is lower than 10% WA close to 15 days. It becomes catastrophically long at 35 days. At present conditions this habitat level corresponds with flows of 0.16 cfsm (5 cfs). If habitat was improved by restoration the same flows would increase the GRAF habitat three fold to 26% WA. The rare events are when GRAF habitat is lower than 7% WA for no longer then 5 days. If it lasts for longer then 5 days, it creates persistent stress and we recommend that it will not happen more often than once in 3 years. The rare event flow will be catastrophic if it lasts for more than 32 days and it should not happen more often than every 10 years. At present conditions this habitat level corresponds with flows of 0.1 cfsm (3 cfs). If habitat was improved by restoration the same flows would increase the GRAF habitat three fold to 22% of wetted area

In Reach 2 commonly ATS habitat stays under 12% WA for no longer than 28 days, but 42 days are catastrophic duration. At present conditions this habitat level corresponds with flows of 0.12 cfsm (8 cfs). If habitat was improved by restoration the same flows would not provide much more habitat (15% WA). Critical events begin if habitat is lower than 4% WA for durations close to 18 days. It becomes catastrophically long at 35 days. At present conditions this habitat level corresponds with flows of 0.04 cfsm (3 cfs). If habitat was improved by restoration the same flows would increase the ATS habitat only to 5% WA. The rare events are when ATS habitat is lower than 2% of wetted area for no longer then 10 days. The drought will be catastrophic if it lasts for more than 15 days. At present conditions this habitat level corresponds with flows of 0.02 cfsm (1 cfs). For ATS no net habitat gain is provided at these flows with restoration.

In Reach 3 we used YOY habitat as an indicator for necessary flows. Commonly YOY habitat stays under 7% WA for no longer than 30 days, but 45 days are catastrophic duration. At present conditions this habitat level corresponds with flows of 0.21 cfsm (21 cfs). If habitat was improved by restoration the same flows would not provide much more habitat (7% WA). Critical events begin if habitat is lower than 1.5% WA close to 17 days. It becomes catastrophically long at 40 days. At present conditions this habitat level corresponds with flows of 0.13 cfsm (13 cfs). If habitat was improved by restoration the same flows would stay similar 2% WA. The rare events are when YOY habitat is lower than 1% of wetted area for no longer then 10 days. The drought will be catastrophic if it lasts for more than 35 days. At present conditions this habitat level corresponds with flows of 0.1 cfsm (10 cfs). For GRAF no net habitat gain is provided at these flows with restoration.

In Reach 4 commonly YOY habitat stays under 30% WA for no longer than 28 days, but 42 days are catastrophic duration already. At present conditions this habitat level corresponds with flows of 0.6 cfsm (83 cfs). If habitat was improved by restoration the same flows would nearly double the habitat (55% WA). Critical events begin if habitat is lower than 22.5% WA close to 10 days. It becomes catastrophically long at 15 days. At present conditions this habitat level corresponds with flows of 0.11 cfsm (15 cfs). If habitat was improved by restoration the same flows would increase the YOY habitat to 52% WA. The rare events are when YOY habitat is lower than 20% of wetted area for no longer then 5 days. The drought will be catastrophic if it lasts for more than 10 days. At present conditions this habitat level corresponds with flows of 0.1 cfsm (14 cfs). Again substantial habitat gain can be accomplished at these flows with restoration (52% WA).

In Reach 5 flows we used Atlantic salmon habitat as an indicator for necessary flows. Commonly the habitat stays under 5.5% WA for no longer than 30 days, but 42 days are catastrophic duration. At present conditions this habitat level corresponds with flows of 0.31 cfsm (43 cfs). If habitat was improved by restoration the same flows would provide minor additional habitat for salmon (6% WA). Critical events begin if habitat is lower than 5.2% WA close to 17 days. It becomes catastrophically long at 20 days. At present conditions this habitat level corresponds with flows of 0.15 cfsm (21 cfs). If habitat was improved by restoration the same flows would not change habitat availability for this species. The rare events are when salmon habitat is lower than 5% of wetted area for no longer then 5 days. The drought will be catastrophic if it lasts for more than 10 days. At present conditions this habitat level corresponds with flows of 0.11 cfsm (15 cfs). Again no habitat gain can be accomplished at these flows with restoration (5% WA).

In Reach 6 commonly GRAF habitat stays under 34% WA for no longer than 20 days, 40 days are catastrophic duration. At present conditions this habitat level corresponds with flows of 0.12 cfsm (19 cfs). If habitat was improved by restoration the same flows would not provide more habitat (33% WA). Critical events begin if habitat is lower than 27% WA close to 15 days. It becomes catastrophically long at 27 days. At present conditions this habitat level corresponds with flows of 0.1 cfsm (16 cfs). If habitat was improved by restoration the same flows would not increase the GRAF habitat (27% WA). The rare events are when GRAF habitat is lower than 22% of wetted area for no longer then 7 days. The drought will be catastrophic if it lasts for more than 15 days. At present conditions this habitat level corresponds with flows of 0.08 cfsm (13 cfs). Again no substantial habitat gain can be accomplished at these flows with restoration (22% WA).

In Reach 7 commonly YOY habitat stays under 23% WA for no longer than 23 days, 40 days are catastrophic duration. At present conditions this habitat level corresponds with flows of 0.12 cfsm (19 cfs). If habitat was improved by restoration the same flows would provide some more habitat (29% WA). Critical events begin if habitat is lower than 19% WA close to 15 days. It becomes catastrophically long at 27 days. At present conditions this habitat level corresponds with flows of 0.08 cfsm (13 cfs). If habitat was improved by restoration the same flows would increase the YOY habitat to 22 % WA. The rare events are when YOY habitat is lower than 18% of wetted area for no longer then 5 days. The drought will be catastrophic if it lasts for more than 10 days. At present conditions this habitat level corresponds with flows of 0.05 cfsm (8 cfs). A slight habitat gain can be accomplished at these flows with restoration (19% WA).

Recommendation

For the Upper Souhegan, the flows should not commonly fall under 0.3 cfsm (31 cfs) for longer than 30 days, nor under 0.16 cfsm (16 cfs) for 15 days, nor under 0.1 cfsm (10 cfs) for 5 days. This rule should not be violated more often than once in three years. Catastrophic durations for these levels are 42, 35, and 30 days, respectively.

For the Lower Souhegan, the flows should not commonly fall under 0.6 cfsm (103 cfs) for longer than 20 days, nor under 0.15 cfsm (26 cfs) for 15 days, nor under 0.1 cfsm (17 cfs) for 5 days. This rule should not be violated more often than once in three years. Catastrophic durations for these levels are 40, 20 and 10, days, respectively.

Atlantic Salmon Spawning Bio-period (October 1 through November 15)

For the Upper Souhegan segment, Reach 2 was selected as the most flow sensitive Atlantic salmon spawning habitat. Commonly the habitat does not stay under 50% WA for longer than 30 days, and a duration of 40 days is already catastrophic. This corresponds with flows of 0.4 cfsm (26 cfs). The critical levels begin below 6% WA (0.1 cfsm – 8 cfs) which should not last longer than 12 days. 30 days of habitat under this level is already catastrophic. According to UCUT analysis the rare events are when habitat drops under 1% (0.6 cfsm – 1 cfs). Those may last up to 10 days and are catastrophic with duration over 23 days (Table 17).

Table 17. Recommended flow criteria for Atlantic salmon spawning bio-period.

Indicator	ATS	ATS	Recommended flows	
Location	**Reach 2**	**Reach 5**	**Upper**	**Lower**
Gauge (SR#)	16-18	31-34	25	USGS
Watershed area (mi^2)	64.6	139	102	171
Common habitat (% WA)	**50**	**15**		
Allowable duration under (days)	30	20	30	23
Catastrophic duration (days)	40	40	40	40
Corresponding flow present (cfsm)	0.4	1.05	0.4	1.1
Common flow (cfs)	16	146	41	184
Critical habitat	**6**	**6**		
Allowable duration under (days)	12	12	12	12
Catastrophic duration (days)	30	40	30	40
Corresponding flow present (cfsm)	0.1	0.4	0.1	0.6
Critical flow (cfs)	6	56	10	96
Rare habitat (%WA)	**1**	**5**		
Allowable duration under (days)	10	5	10	5
Catastrophic duration (days)	23	10	23	10
Corresponding flow present (cfsm)	0.1	0.25	0.1	0.4
Rare flow (cfs)	6	35	10	70

For the Lower Souhegan, Reach 5 was selected as the most flow sensitive Atlantic salmon spawning habitat. Commonly the habitat does not stay under 15% WA for longer than 20 days, and duration of 40 days is already catastrophic. This corresponds with flows of 1.05 cfsm (146 cfs). The critical levels begin below 6% WA (0.4 cfsm – 56 cfs) which should not last longer than 12 days. 40 days of habitat under this level is already catastrophic. According to UCUT analysis the rare events are when habitat drops under 5% (0.25 cfsm – 35 cfs). Those may last up to 5 days and are catastrophic with duration over 10 days (Table 16).

Recommendation

The rare flow levels computed for the Upper Souhegan during this bio-period using Atlantic salmon spawning habitat needs are 0.06 cfsm. This flow is lower than that necessary for GRAF species (0.1 cfsm). Because the habitat is used by both Atlantic salmon and GRAF, it is recommended to use the criteria for GRAF species as developed for the R&G bio-period. Therefore the value for rare flows in Table 17 has been rounded up to 0.1cfsm. The GRAF UCUTs remain the same for the time period of October 1 through November 15.

For the Lower Souhegan it is recommended that flows at the USGS gage remain under 184 cfs, 96 cfs, and 70 cfs for no longer than 23 days, 12 days, and 5 days, respectively, no more often than once in 3 years. In catastrophic situations of the decadal scale it may be lower for 40 days, 40 days, and 10 days, respectively.

Overwintering Bio-period (November 15 through February 28)

During this season no habitat data were available and flow recommendations were based on UCUT analysis of simulated flows at the USGS gage in Merrimack (Table 18). It is recommended that flows not be lower than 342 cfs, 85.5 cfs, and 51 cfs for longer than 35, 15, and 5 days, respectively. Catastrophic durations are 50, 30, and 10 days for these levels.

Table 18. Recommended flow criteria for overwintering bio-period.

Indicator	Recommended
Gauge	USGS
Watershed area	171
Common habitat (% WA)	
Allowable duration under (days)	35
Catastrophic duration (days)	50
Corresponding flow present (cfsm)	2
Common flow (cfs)	342
Critical habitat	
Allowable duration under (days)	15
Catastrophic duration (days)	30
Corresponding flow present (cfsm)	0.5
Critical flow (cfs)	85.5
Rare habitat (%WA)	
Allowable duration under (days)	5
Catastrophic duration (days)	10
Corresponding flow (cfsm)	0.3
Rare flow (cfs)	51.3

Spring flood bioperiod (March 1 through April 30)

For lack of habitat information no rules, are developed for this season. The guide used by NH Fish and Game is the median February flow (1.1 cfsm for the Souhegan River). The recommended overwintering flow is 0.3 - 0.5 cfsm.

American shad bioperiod (May 1 through June 14)

For The Upper Souhegan segment, Reach 2 was selected as being the most flow sensitive American shad spawning habitat. Commonly the habitat does not stay under 70% WA for longer than 25 days and duration of 40 days is already catastrophic. This corresponds with flows of 2.1 cfsm (136 cfs). The critical levels begin below 30% WA (0.6 cfsm – 39 cfs) which should not last longer than 10 days. 15 days of habitat under this level is already catastrophic. The rare events are when habitat drops under 25% WA (0.4 cfsm – 24 cfs). Those may last up to 4 days and are catastrophic with duration over 7 days (Table 19).

Table 19. Recommended flow augmentation criteria for American Shad bio-period.

Indicator	GRAF	GRAF	**Recommended flows**	
Gauge (SR#)	16-18	31-34	25	USGS
Watershed area (mi^2)	64.6	139	102.3	171
Location	**Reach 2**	**Reach 5**	**Upper**	**Lower**
Common habitat (% WA)	**70**	**80**		
Allowable duration under (days)	25	15	25	15
Catastrophic duration (days)	40	25	40	25
Corresponding flow present (cfsm)	2.1	1	2.1	1.0
Common flow (cfs)	136	139	215	178
Critical habitat (% WA)	**30**	**40**		
Allowable duration under (days)	10	5	10	5
Catastrophic duration (days)	15	10	15	10
Corresponding flow present (cfsm)	0.6	0.4	0.6	0.6
Critical flow (cfs)	39	56	61	96
Rare habitat (% WA)	**25**	**35**		
Allowable duration under (days)	4	5	4	5
Catastrophic duration (days)	7	10	7	10
Corresponding flow (cfsm)	0.37	0.35	0.37	0.5
Rare flow (cfs)	24	49	38	88

For the Lower Souhegan Reach 5 was selected as the one with the most flow sensitive American shad spawning habitat. Commonly the habitat does not stay under 80% WA for longer than 15 days and duration of 25 days is already catastrophic. This corresponds with flows of 1 cfsm (139 cfs). The critical levels begin below 40% WA (0.4 cfsm – 56 cfs) which should not last longer than 5 days. 10 days of habitat under this level is already catastrophic. The rare events are when habitat drops under 35% (0.11 cfsm – 15 cfs). Those may last up to 5 days and are catastrophic with duration over 10 days (Table 19).

Recommendation

For the Upper Souhegan, the flows should not commonly fall under 2.1 cfsm (215 cfs) for longer than 25 days, nor under 0.6 cfsm (61 cfs) for 10 days nor under 0.37 cfsm (38 cfs) for 4 days. This rule should not be violated more often than once in 3 years. Catastrophic durations for these levels are 40, 15, and 7 days, respectively.

For the Lower Souhegan the flows should not commonly fall under 1 cfsm (178 cfs) for longer than 25 days, nor under 0.6 cfsm (96 cfs) for 5 days, nor under 0.5 cfsm (88 cfs) for 5 days. This rule should not be violated more often than once in 3 years. Catastrophic durations for these levels are 25, 10, and 10 days, respectively. Table 19 presents distribution of these flows in reaches as computed using the concurrent flow power functions.

GRAF spawning bio-period (June 15 through July 14)

For the Upper Souhegan segment, Reach 2 was selected as providing the most flow sensitive GRAF spawning habitat. Commonly the habitat does not stay under 30% WA for longer than 20 days and duration of 27 days is already catastrophic. This corresponds with flows of 0.23 cfsm (15 cfs). The critical levels begin below 10% WA (0.11 cfsm – 7 cfs) which should not last longer than 10 days. 20 days of habitat under this level is already catastrophic. The rare events are when habitat drops under 5% WA (0.08 cfsm – 5 cfs). Those may last up to 5 days and are catastrophic with duration over 15 days (Table 20).

Table 20. Recommended flow augmentation criteria for GRAF spawning bio-period.

Indicator	GRAF	GRAF	**Recommended flows**	
Gauge	16-18	31-34	25	USGS
Watershed area	64.6	139	102.3	171
	Reach 2	**Reach 5**	**Upper**	**Lower**
Common habitat (% WA)	**30**	**10**		
Allowable duration under (days)	20	17	20	17
Catastrophic duration (days)	27	25	27	25
Corresponding flow present (cfsm)	0.23	0.11	0.23	0.23
Common flow (cfs)	15	15	24	39
Critical habitat	**10**	**5**		
Allowable duration under (days)	10	13	10	13
Catastrophic duration (days)	20	23	20	23
Corresponding flow present (cfsm)	0.11	1.4	0.11	1.4
Critical flow (cfs)	7	195	11	239
Rare habitat (%WA)	**5**	**4**		
Allowable duration under (days)	10	10	10	10
Catastrophic duration (days)	15	10	15	10
Corresponding flow (cfsm)	0.08	1.9	0.08	1.9
Rare flow (cfs)	5	264	8	325

For the Lower Souhegan, Reach 5 was selected as the reach with the most flow sensitive GRAF spawning habitat. Commonly the habitat does not stay under 11% WA for longer than 17 days and duration of 25 days is already catastrophic. This corresponds with flows of 0.11 cfsm (15 cfs). The critical levels begin below 5% WA (1.4 cfsm – 195 cfs) which should not last longer than 13 days. 23 days of habitat under this level is already catastrophic. The rare events are when habitat drops under 4% (1.9 cfsm – 264 cfs). Those may last up to 10 days and are catastrophic with duration over 10 days (Table 20).

Recommendation

As presented earlier, during early summer the spawning habitat for GRAF species mostly declines with flow increase. Therefore on this bio-period the recommendations are different than for other seasons. It is recommended to target flow levels and durations rather than downward limitations of flows.

For the Upper Souhegan the flows should commonly last under 0.23 cfsm (24 cfs) for 20 days, but not below 0.11 cfsm (11 cfs) for more than 10 days. This rule should not be violated more often than once in 3 years. Catastrophic durations are if flows stay under 8 cfs for longer than 15 days.

For the Lower Souhegan the flows should stay under 0.23 cfsm (39 cfs) for at least 17 days, but no longer than 25 days. Flow should not be above 1.4 cfsm (239 cfs) for longer than 13 days (23 days in catastrophic case). The flows should not be higher than 1.9 cfsm (325 cfs) for longer than 10 days. Catastrophic durations for these two levels are 10 days or more. This indicates that in order to support spawning, the long durations of high flow events are rare and should be avoided or controlled. On the low flow end, rare flows cannot be lower than in the adjacent R&G season, because the adult fish still need to survive. Hence, the PISF is set at 0.1 cfsm.

Discussion

Analysis of fish fauna status suggests that the fish community was affected by factors other than habitat availability. High water temperatures and poor water quality may be the other factors. Temperature and pollution intolerant species are strongly underrepresented or missing in the existing fish community. Other than juvenile Atlantic salmon, diadromous species are absent in the Souhegan River. The physical habitat was not a limiting factor for diadromous species to the extent that would justify their absence. In contrast, American eel had greater habitat availability than all other species in the Upper Souhegan. Anadromous species (did not seem to be or) were not limited by habitat availability, but may not have access to the habitat that was available. There were high amounts of available spawning habitat for American shad in the Upper Souhegan, but (with exception of Reach 2) less for Atlantic salmon. Juvenile Atlantic salmon habitat was well represented in the upper most reaches (Reach 1 and 2). This is essential considering all of the effort invested in the restoration of these species. Brook trout and slimy sculpin also have available habitat in the Upper Souhegan. These fish were not found in the Upper Souhegan during the study and their absence can be explained by the summer water temperatures, which almost consistently stayed above the lethal levels for these species.

White sucker may be/are limited by flow-dependent habitat availability and lack of access to that habitat. In general the existing community structure of the resident fauna corresponded with the target community for the Souhegan River, however in the Upper Souhegan the proportions of fluvial dependant and generalist species are lower than in the TFC. Particularly, an under representation of white sucker (fluvial dependent) is apparent. In the Upper River underrepresentation may be caused by low amounts of physical habitat, which for white sucker and common shiner occurs in similar ratio as the proportions of fish found in the sample. The habitat availability increases with flow. In the Lower Souhegan white sucker is also underrepresented but the reasons may be different as the proportions of habitat are higher than observed. It is also unlikely caused by lack of habitat for juvenile and larval fish, because YOY habitat was found in large quantities in the entire river. Abundant spawning habitat was also found, most notably for white sucker. However, the majority of the white sucker spawning habitat occurs in the Upper Souhegan, upstream of Wilton, an area not accessible for individuals from the lower river because of numerous dams. White sucker is known for long spawning migration and could be easily limited by this habitat fragmentation. Moreover instantaneous flow fluctuations connected to hydropower generation were observed on the Souhegan River during the period of study and it is recommended that such fluctuations be avoided during the spawning bio-period. White sucker are broadcast spawners with long incubation times, and therefore may not get the required gestation period if eggs are exposed to air through flow fluctuations.

Common shiner is also under represented in the Upper River and, similarly to white sucker, the habitat proportions correspond with fish proportions in the community. In the lower river, however, the abundance of this species is higher than expected, which corresponded well with relatively abundant spawning habitat for this species. Because spawning requirements of common shiner are not as stringent as those of white sucker this observation further supports the previously mentioned conclusions.

This investigation documented that the overall fish abundances were low. The R&G habitat for GRAF species usually comprised less than one third of the wetted area. This could be improved with simple restoration measures such as adding woody debris and canopy cover. It is expected that the physical habitat at these levels is not the only limiting factor; however it may lower the ability of fish fauna to resist the stress caused by high temperatures.

Although fish habitat is not overabundant; it is stable over the range of the investigated flows. Only in the Upper Souhegan did the rating curves document flow sensitivity of habitat, particularly at the low flow conditions. This is an important consideration for the Souhegan River because historic records exhibited a high frequency of very low flows in the summer and fall. Even simulated flow time series exhibit the same pattern, particularly during the summer and early fall seasons. Therefore, the maintenance of appropriate frequency and duration of such flow events is important and may require some directed flow releases that would bring the habitat from the rare to common level. In early summer (June 15 to July 15) lower flows may actually support resident fauna spawning efforts, which would allow water to be stored for augmentation later in the summer. The augmentation (relief) flows are usually not very high, and maybe needed for a short period of time to create relief for the stressed fauna. We propose that the augmentation pulses last for at least two days. This duration is approximately corresponding with natural events and assures that very short, instantaneous flow fluctuations will not be mistaken for augmentation releases. Table 21 presents the final recommendation for seasonal flow regimes regulated separately for the upper and lower Souhegan River. We recommend installation of additional flow gauging

Table 21. Recommended flow criteria for fish (bold values are flows not to be exceeded)

Bioperiod	**Rearing & Growth**		**Salmon Spawning**		**Over-Wintering**	
Approximate dates	July 15 - Sept. 30		Oct. 1 - Nov. 14		Nov. 15 - Feb. 28	
	Recommended flows		**Recommended flows**		**Recommended flows**	
Concurrent Gauge (SR#)	SR 25	USGS	SR 25	USGS	SR 25	USGS
Watershed area (mi^2)	102	171	102	171	102	171
Location	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
Common flow (cfs)	31	103	41	184		342
Common flow (cfsm)	0.3	0.6	0.4	1.1	1.1	2.0
Allowable duration under (days)	30	20	30	23		35
Catastrophic duration (days)	42	40	40	40		50
Critical flow (cfs)	16	26	10	96		86
Critical flow (cfsm)	0.16	0.15	0.1	0.6	0.5	0.5
Allowable duration under (days)	15	15	12	12		15
Catastrophic duration (days)	35	20	30	40		30
Rare flow (cfs)	10	17	10	70		51
Rare flow (cfsm)	0.1	0.1	0.1	0.4	0.3	0.3
Allowable duration under (days)	5	5	10	5		5
Catastrophic duration (days)	30	10	23	10		10
Bioperiod	**Spring Flood**		**Shad Spawning**		**GRAF Spawning**	
Approximate dates	March 1 - April 30		May 1 - June 14		June 15 - July 14	
	Recommended flows		**Recommended flows**		**Recommended flows**	
Concurrent Gauge (SR#)	SR 25	USGS	SR 25	USGS	SR 25	USGS
Watershed area (mi^2)	102	171	102.3	171	102.3	171
Location	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
Common flow (cfs)	N/A	N/A	215	178	24	39
Common flow (cfsm)	1.1	1.1	2.1	1.0	0.23	0.23
Allowable duration under (days)	N/A	N/A	25	15	20	17
Catastrophic duration (days)	N/A	N/A	40	25	27	25
Critical flow (cfs)	N/A	N/A	61	96	11	**239**/19
Critical flow (cfsm)	0.4	0.4	0.6	0.6	0.11	**1.4**/0.11
Allowable duration under (days)	N/A	N/A	10	5	10	**13**
Catastrophic duration (days)	N/A	N/A	15	10	20	**23**
Rare flow (cfs)	N/A	N/A	38	88	8	**325**/19
Rare flow (cfsm)	0.3	0.3	0.37	0.5	0.08	**1.9**/0.11
Allowable duration under (days)	N/A	N/A	4	5	10	**10**
Catastrophic duration (days)	N/A	N/A	7	10	15	**10**

station in reach 3, section 25. The readings at this gauge should be used for managing flows in the upper Souhegan. During the performance of this study, relatively high levels of mussel and odonate habitat in the Lower Souhegan were identified. Mussel habitat did not appear to be flow sensitive (instead preferring fine substrates) and was therefore not presented in the rating curves. Reach 5 was the richest in this fauna in terms of found individuals as well as habitat. The odonate habitat is flow sensitive with a preference to lower flows.
In general Reaches 2 and 5 were of the highest habitat quality for investigated fauna. Reach 2 had a particularly high amount of spawning habitat. Reach 3 exhibited the highest level of impairment. Beginning with Reach 6 the character of the river changed to one more suitable for generalist species, hence the habitat quantity and quality gradually dropped.

Table 22 presents a score card of recommended priority management areas for the Souhegan River by reaches. The most important management issue at this time is a reduction of the thermal impact caused by upstream impoundments. This can be accomplished by improvements at the source (reservoir structure modifications) and by increasing resilience of aquatic fauna through favorable physical habitat. The primary measures are to secure more natural frequency and duration of favorable habitat levels (pulsed flow augmentation) as well as by increasing the diversity and richness of habitat structure (channel improvements by adding large woody debris, shading, and defragmentation).

Table 22. The priority and importance of various aspects for maintenance and restoration of the aquatic fauna. Red indicates critical issues or areas. Yellow indicates areas of concern. Green indicates the reaches with the highest habitat quality.

	Reach 1	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Reach 6**	**Reach 7**
Temperature and Water Pollution							
Flow							
Fish Passage							
Stream Improvements							

Part 2. Hydrographs

I.) Representative Hydrographs

Daily streamflow data for the Souhegan River were collected from the United States Geological Survey (USGS) Merrimack gage (gage no. 01094000). The gage is located just upstream of the Souhegan River confluence with the Merrimack River, at the head of Wildcat Falls. The Souhegan River gaging station was inactive from Water Year 1977 to 2001. The nearby Stony Brook gage was used to estimate Souhegan flows for the missing time period.

Streamflow values at 10 locations upstream of the USGS gage (see Table 23) were estimated from concurrent flow measurements that were conducted for flows ranging from 0 to 1 cfsm. Measured flows were scaled by watershed area to determine flow values in cfsm and then correlated to the USGS measured flows (also converted to cfsm). Given the relatively close proximity of some study reaches, four lumped relationships were developed from combined concurrent flow measurements at two neighboring locations. Representative hydrographs were developed for the following scenarios: last five years, wet three years, average three years, and dry three years. A 30-year hydrograph was developed to aid with the development of the CUT curves for fisheries habitat. Details of how the periods were developed may be found in Appendix 3.

The streamflow record from water years 1910 to 2004 was used to identify the three-year periods having wet, dry, and average conditions. In addition, streamflow values for the last five years and a 30-yr period were identified. Three-year average streamflow values were determined using a three-year moving window. When available, the annual precipitation record was examined to support the selection of the three-year periods. The maximum average flow (376.0 cfs) occurred from 1951 to 1953 and had a correspondingly high precipitation value of 48.4 in. The minimum average flow (154.4 cfs) occurred from 1964 to 1966 and was preceded by the lowest average annual precipitation (31.8 in) from 1963 to 1965. Average conditions (283.1 cfs) were found from 1994 to 1996. Similar average streamflow also occurred from 1945-1947 (284.8 cfs). The latter will be used as the 1945 to 1947 data were measured while the 1994 to 1996 data were estimated from the Stony Brook gage data. The average streamflow over the last five years (262.8 cfs) was slightly below the long-term average conditions. The selected 30-yr period is 1948 to 1977. This period includes historical wet and dry periods and has an average flow (286.5 cfs) that is close to the long-term average. These representative hydrographs are compared to the 70 years of record at the Merrimack gage in Figure 45, in which the comparison is made with a flow duration plot. Figure 46 amplifies the low and high flows of the flow duration curves of Figure 45. Here it can be seen that the dry 3-year record possesses significantly lower flows, but also that the wet 3-year record has lower low flows than the average 3-year record. For the high flows, the hydrographs subscribe to their expected order, and the last 5 year hydrograph is wetter than the average.

Table 23. Concurrent flow results for locations upstream of the Souhegan River USGS gage using the relationship $Q_{upstream, cfsm} = a . Q_{USGS, cfsm}^b$. Concurrent flows were measured from 0 to 1 cfsm. Accuracy of relationships decrease outside the measured range.

Site	Description	Area (mi^2)	Ratio to USGS gage	Num. of Measures	a	b	R^2
SR6	Handicap Access Fish Ramp - Greenville	33.9	0.198	4	0.6078	0.7774	0.962
SR12	High Energy Bank - Greenville	37.0	0.216	4	0.6307	0.7819	0.731
SR6/SR12				8	0.6189	0.7793	0.830
SR16	Upstream of Monadnock Water	64.6	0.377	3	1.0478	1.599	0.995
SR18	Intervale Road - Wilton	65.0	0.379	2	0.8505	1.2962	1.000
SR16/18				5	0.9437	1.4540	0.984
SR25	Wilton wastewater pumping station	102.3	0.597	4	0.5947	1.0369	0.824
SR31	Shopping Center Mall - Milford	127.2	0.743	3	0.964	1.3287	0.991
SR34	Electric Substation - Milford	139.4	0.814	3	1.0151	1.4825	0.984
SR31/34				6	0.996	1.4159	0.981
SR50	Boston Post Road - Amherst	159.0	0.928	3	0.9573	1.3073	0.979
SR56	Tomalison Farm - Amherst	165.6	0.967	3	0.9726	1.3207	0.996
SR50/56				6	0.9649	1.314	0.987
SR62	Turkey Hill Road – Amherst	169.4	0.989	2	0.8233	1.0098	1.000
USGS	USGS Gage	171.3	1.000	N/A	N/A	N/A	N/A

The representative hydrographs include the historic net withdrawals (withdrawal minus return flow) in the watershed upstream of the Merrimack gage. To consider the impact of AWU withdrawals, net of return flow, a monthly record of net withdrawals was created. Here, all long term water use data from AWUs, not just direct and induced recharge, were considered. These withdrawals include groundwater pumping values and the historic surface water withdrawals. Documented return flows were also included. Average values from 2000-2004 were used to estimate monthly gross and net water use for each AWU. Net water use (equivalently consumptive water use) was estimated by multiplying the gross use by a consumptive loss rate. Values were summarized by stream reach and used to create monthly losses by reach (Figure 47). The resulting withdrawal minus return flow (cfsm) monthly values are added to the representative hydrographs for each reach to generate streamflow records without the impact of AWUs withdrawals.

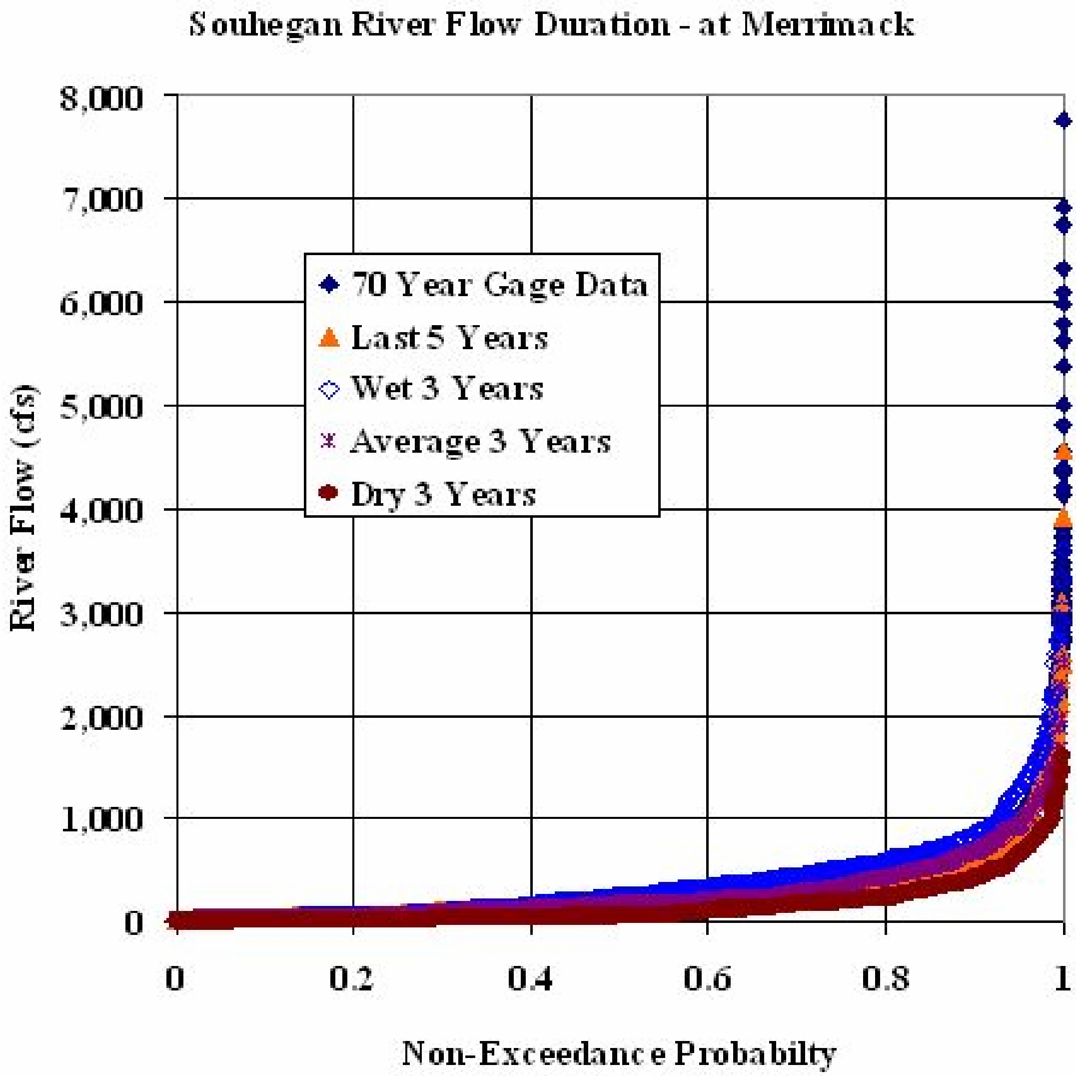


Figure 45. Full Flow Frequency Plot for the Various Souhegan River Datasets at the USGS Gage.

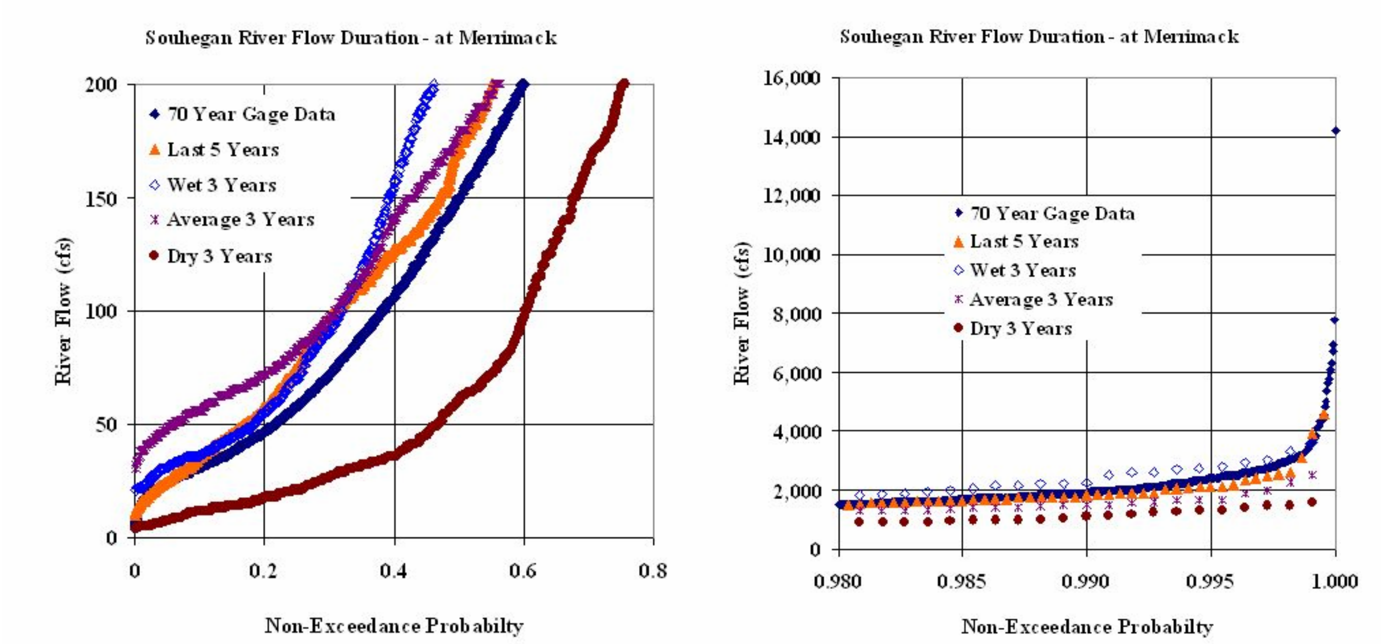


Figure 46. Amplification of low and high flow duration curves for selected hydrographs at the USGS gage.

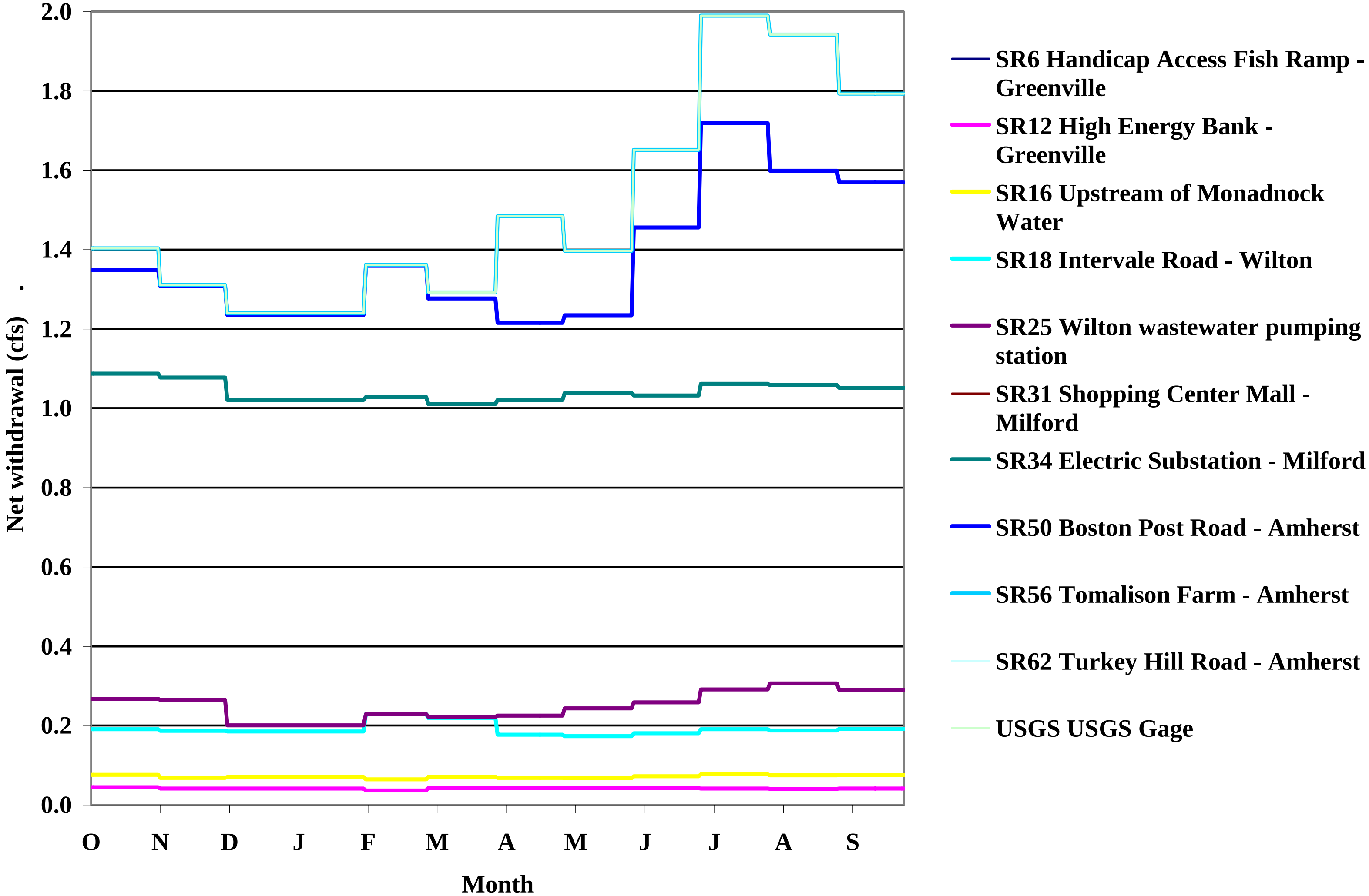


Figure 47. Monthly net withdrawal minus return flow (cfs). Values are to be added to the 5-year hydrograph for each reach.

II.) Comparison of PISF to Representative Hydrographs

All recommended PISF were compared to the untransformed representative hydrographs. This comparison then demonstrates how the existing system, including withdrawals and return flows, meets the PISF.

Recreation

The recommended PISF for recreation is 4 cfsm in Reaches 1 and 2 and no recommended PISF downstream of Reach 2. These comparisons are coarse estimates since the regression equations were calibrated only up to 1 cfsm. Table 24 delineates the number of days that the representative hydrographs meet the recreation PISF.

Fishing

The recommended fishing PISF Use is dependent on the Souhegan River flow only to the extent that it protects the fishery resource. Therefore this section defers the PISF to that for fish habitat.

Table 24. Comparison of Existing System Streamflow to the Recreation PISF. (number of days per year the reach meets the PISF and fraction of time in the representative hydrograph).

Representative Hydrograph	Reach 1		Reach 2	
	Days	%	Days	%
Last five years	11	0.60	290	15.9
Wet three years	19	1.74	309	28.2
Average three years	4	0.37	198	18.1
Dry three years	0	0.00	94	8.6

Hydropower

The hydropower PISF is 0.7 cfsm in Reach 1 and 0.44 cfsm in Reach 3. No other hydropower PISF are specified. Table 25 delineates the number of days that the representative hydrographs meet the hydropower PISF.

Pollution Abatement

The pollution abatement PISF is 0.067 cfsm for all Reaches. Table 26 delineates the number of days that the representative hydrographs do not meet the pollution abatement PISF. The wet hydrographs demonstrates more times when the flow falls below 0.1 cfsm than the average hydrograph. This is because there were dry periods at the very start and very end of the wet hydrograph (see flow comparison between these two three-year hydrographs in Figure 47).

Table 25. Comparison of Existing System Streamflow to the Hydropower PISF. (number of days per year the reach meets the PISF and fraction of time in the representative hydrograph).

Representative Hydrograph	Reach 1		Reach 3	
	Days	%	Days	%
Last five years	561	17.9	520	35.6
Wet three years	590	53.9	570	52.1
Average three years	479	43.7	624	57.0
Dry three years	267	24.4	351	32.0

Table 26. Comparison of Existing System Streamflow to the Pollution Abatement PISF. (number of days per year each reach does not meet the PISF and fraction of time in the representative hydrograph).

Representative Hydrograph	Reach 1		Reach 2		Reach 3		Reach 4	
	Days	%	Days	%	Days	%	Days	%
Last five years	0	0.0	133	9.1	63	4.3	111	7.6
Wet three years	0	0.0	38	3.5	2	0.2	26	2.4
Average three years	0	0.0	0	0.0	0	0.0	0	0.0
Dry three years	90	8.2	343	31.3	282	25.7	316	28.8

Representative Hydrograph	Reach 5		Reach 6		Reach 7		Reach 8	
	Days	%	Days	%	Days	%	Days	%
Last five years	111	7.6	74	5.1	74	5.1	1	0.1
Wet three years	26	2.4	13	1.2	13	1.2	0	0.0
Average three years	0	0.0	0	0.0	0	0.0	0	0.0
Dry three years	316	28.8	289	26.4	289	26.4	102	9.3

Water Supply

Water supplies do not have recommended PISF.

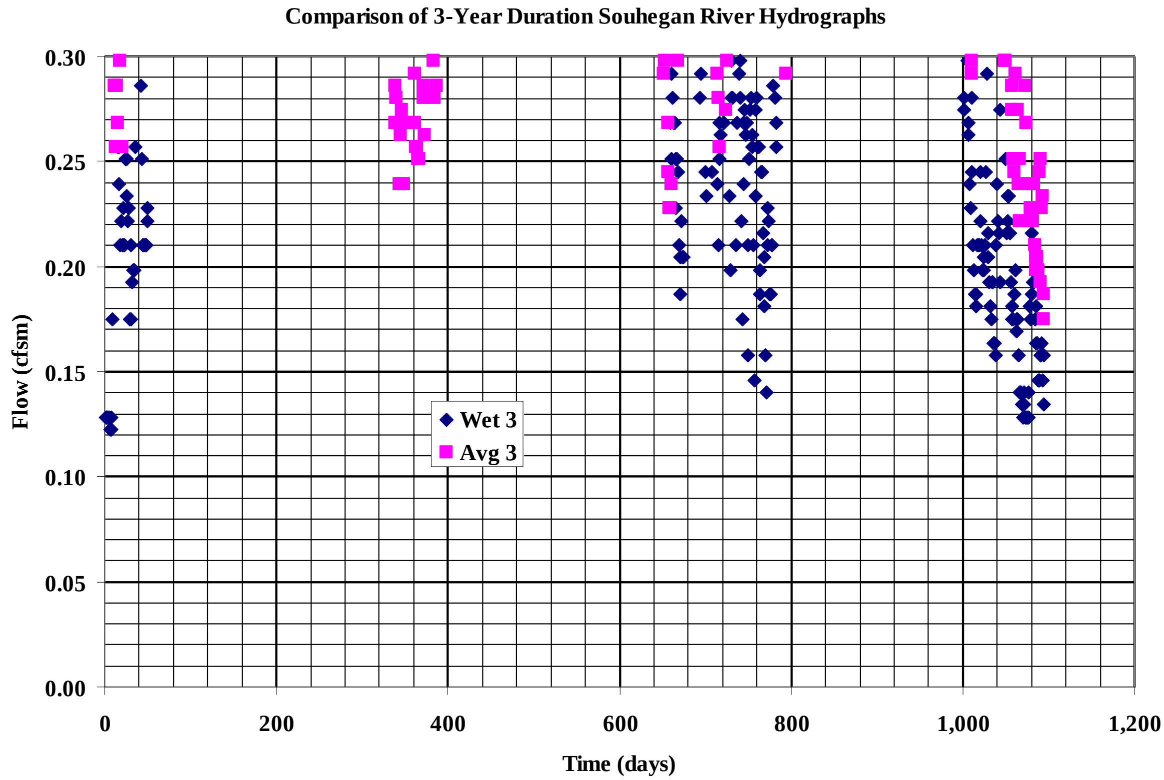


Figure 48. Comparison of the lowest flow data points in the "wet" and "average" three year hydrographs.

RTE: Fish, wildlife, vegetation, and natural/ecological communities

A. Rare, Threatened, and Endangered Wildlife

Wood Turtle (Clemmys insculpta)

The summer PISF for the Wood Turtle are flows less than 5.85 cfsm in Reaches 7 and 8 from June through September. In the winter, the December through February flow should exceed the previous average late October- November flow, also in Reaches 7 and 8. Table 27 displays the comparisons of the Wood Turtle PISF to the flows in the representative hydrographs. For the winter flow, the median Oct. 20 – Nov. 30 flow at the USGS gage is 131 cfs (0.97 cfsm), and this is used as the Dec. – Feb. wood turtle PISF. Flows below this PISF may cause harm to hibernating Wood Turtles, but this effect could be moderated by warm air temperatures, large proportion of non-hibernating turtles, and lower than average water levels in October and November when turtles select hibernacula. The high flow comparisons are estimates, since the regression equations for the flows along the river were only calibrated up to 1 cfsm.

Table 27. Comparison of Existing System Streamflow to the Wood Turtle PISF. (Days - number of days in each reach representative hydrograph that the river flow does not meet the PISF and % - fraction of time in the representative hydrograph the PISF is not met). The majority of the winter PISF failures are due to lower flows in late February in the five year record.

Summer

Representative Hydrograph	Reach 7		Reach 8	
	Days	%	Days	%
Last five years	21	1.4	1	0.07
Wet three years	3	0.4	2	0.0
Average three years	5	0.5	1	0.1
Dry three years	0	0.0	0	0.0

Winter – compare Dec-Feb flows against median of previous Oct20-Nov30 flows

Representative Hydrograph	Reach 7		Reach 8	
	Days	%	Days	%
Last five years	155	10.6	155	10.6
Wet three years	40	3.7	40	3.7
Average three years	22	2.0	21	1.9
Dry three years	4	0.4	4	0.4

Winter – compare Dec-Feb flows against median Oct20-Nov30 flow (70-year record) of 0.97 cfsm

Representative Hydrograph	Reach 7		Reach 8	
	Days	%	Days	%
Last five years	238	16.3	190	13.0
Wet three years	13	1.2	9	0.8
Average three years	52	1.8	46	4.2
Dry three years	182	16.6	167	15.3

Fowlers Toad (Bufo fowleri)

Critical water levels for Fowler's and American Toads is standing water at least 3 inches deep (0.25 feet) in backwaters and oxbow marshes (that were flooded during May and June) until mid-August. Flows between 400 cfs (2.335 cfsm) and 600 cfs (3.51 cfsm) at the USGS Merrimack Gage in spring fill the small backwaters located on these transects that do or could serve as breeding pools. Since these are reported as average daily flows, and an average daily flow of 400 cfs has instantaneous flows above 400 cfs, the 400 cfs was used for the PISF. From mid-June through mid-August, flows above 30 cfs (0.175 cfsm) (based on the

MesoHABSIM site maps) maintain standing water in at least some of the oxbow marshes that serve as breeding areas. Table 28 displays the comparisons of the Fowlers Toad PISF to the flows in the representative hydrographs. The high flow comparisons are estimates, since the regression equations for the flows along the river were only calibrated up to 1 cfsm.

Table 28. Comparison of Existing System Streamflow to the Fowlers Toad PISF.

Representative Hydrograph	Reach 7		Reach 7	
	Years flow fills backwater (May-Jun)	%	Years flow inadequate to maintain standing water (Jun-Aug)	%
Last five years	5	100	0	0.0
Wet three years	3	100	0	0.0
Average three years	3	100	0	0.0
Dry three years	3	100	0	0.0

Representative Hydrograph	Reach 8		Reach 8	
	Years flow fills backwater (May-Jun)	%	Days flow inadequate to maintain standing water (Jun-Aug)	%
Last five years	5	100	0	0.0
Wet three years	3	100	0	0.0
Average three years	3	100	0	0.0
Dry three years	2	66.7	0	0.0

Pied-Billed Grebe (Podolymbus podiceps)

No PISF was recommended for the Pied-billed Grebe.

Osprey (Pandion haliaetus)

Flows that are protective of a healthy fish community will be protective of Osprey. Therefore the PISF for Osprey is set at that for fish, and the ability of the Souhegan River to meet these needs may be found in the section pertaining to fish species.

Common Loon (Gavia immer)

Flows that are protective of a healthy fish community will be protective of the Common Loon. Therefore the PISF for Common Loon is set at that for fish, and the ability of the Souhegan River to meet these needs may be found in the section pertaining to fish species.

B. Rare, Threatened, and Endangered Plants

Long's Bitter Cress (Cardamine longii Fern.)

No PISF was recommended for Long's Bitter Cress.

Wild Garlic (Allium canadense)

Wild Garlic is considered to be flow-dependent on higher flows periodic scouring of flood flows). The specific flows are flood flows (10-year return period or higher). To address how the river hydrology meets this condition, the bankfull flow at the USGS gage was estimated from the two-year and 10-year return period floods. This will be subsequently checked with a field determination of the bankfull elevation and the USGS channel geometry from the USGS 9-207 forms for the gage.

The two-year return period flood at the USGS stream gage in Merrimack, NH is 3,200 cfs (18.7 cfsm), and the 10-year flood is 6,160 cfs (36.0 cfsm). The results of these PISF comparisons to the flows in the representative hydrographs may be found in Table 29. Historical average duration and timing of the 2-year and 10-year floods, estimated by Indicators of Hydrologic Alteration, appear in Appendix 3.

Wild Senna (Cassia hebecarpa)

Wild Senna may be partially dependent on floods to maintain canopy openings and for seed dispersal, but is not dependent on low or average flows. As for Wild Garlic, the frequency of flows in excess of bankfull flow was used as the measure of how the river system presently meets this need. The measure of the Wild Senna PISF against the representative hydrographs may be found in Table 29.

Table 29. Comparison of Existing System Streamflow to the Wild Garlic and Wild Senna PISF. (Days – times when the flow exceeds the indicated flood)

Representative Hydrograph	2-year flood		10-year flood	
	Days	%	Days	%
Last five years	2	0.14	0	0.0
Wet three years	2	0.2	0	0.0
Average three years	0	0.0	0	0.0
Dry three years	0	0.0	0	0.0

C. Natural Communities

High Energy Riverbank (Twisted Sedge (Carex torta) Low Riverbank and Fern Glade)

This high energy riverbank is found in reaches 1 and 2. These communities are adapted to daily and seasonal fluctuations in water levels, but permanent alterations to these plant communities could result from reductions in spring flood levels, ice scour, and summer flows. The high flow Twisted Sedge/Fern Glade PISF is 2.8 cfsm. Table 30 identifies the frequency that this PISF is met for the representative hydrographs. The high flow comparisons are estimates, since the regression equations for the flows along the river were only calibrated up to 1 cfsm.

Southern New England Floodplain Forest: Silver Maple (Acer saccharinum) Floodplain Forest

Reaches 6, 7, and 8 contain the Silver Maple floodplain forests. These forests require periodic flooding (every 1-3 years). The PISF is set at 11.7 cfsm to meet this need. Table 31 identifies the frequency that this PISF is not met for the representative hydrographs. The high flow comparisons are estimates, since the regression equations for the flows along the river were only calibrated up to 1 cfsm.

Table 30. Comparison of System Streamflow to Twisted Sedge/Fern Glade PISF.

Representative Hydrograph	Reach 1 High flow	
	Days flow below PISF	%
Last five years	1,443	97.5
Wet three years	1,031	93.9
Average three years	1,049	97.4
Dry three years	1,135	99.3

Representative Hydrograph	Reach 2 High flow	
	Days flow below PISF	%
Last five years	1,179	79.4
Wet three years	697	63.3
Average three years	835	77.4
Dry three years	964	88.8

Table 31. Comparison of Existing System Streamflow to the Silver Maple Floodplain Forest PISF. (Days – times when flow exceeds 11.7 cfsm)

Representative Hydrograph	Reach 6,7		Reach 8	
	Days flow exceeds PISF	%	Days flow exceeds PISF	%
Last five years	57	3.9	9	0.6
Wet three years	70	6.4	16	1.5
Average three years	35	3.2	2	0.2
Dry three years	10	0.9	0	0.0

Southern New England Floodplain Forest: Sycamore (Platanus occidentalis) Floodplain Forest

This forest exits at reach 4. As with other low floodplain communities, the Sycamore Floodplain Forest is dependent on periodic (every one to three years) flooding and scouring to provide nutrients and reduce competition from flood-intolerant plant species. The sycamore forest did not significantly flood at flows of 2,000 cfs (11.7 cfsm) to 3,000 cfs (17.5 cfsm) recorded in April of 2005. This sycamore forest may be a relic feature of much older hydrology (pre-dam). The PISF is set at 18 cfsm. Table 32 identifies the frequency that this PISF is met for the representative hydrographs. The high flow comparisons are estimates, since the regression equations for the flows along the river were only calibrated up to 1 cfsm.

Table 32. Comparison of Existing System Streamflow to the Sycamore Floodplain Forest PISF. (Days – times when flow exceeds 18 cfsm)

Representative Hydrograph	Reach 4	
	Days flow exceeds PISF	%
Last five years	42	2.9
Wet three years	50	4.6
Average three years	18	1.6
Dry three years	4	0.36

Oxbow/Backwater Marsh

These communities are found in reaches 6, 7, and 8. The oxbow and backwater marsh ecosystems need to fill in the spring and have a low water maintenance flow in the summer. The fill period is in the spring (March - May) and the PISF is 3.51 cfsm. The low maintenance flow is 0.2 cfsm from May – September. Table 33 identifies the frequency that this PISF is not met for the representative hydrographs. The high flow comparisons are estimates, since the regression equations for the flows along the river were only calibrated up to 1 cfsm.

Table 33. Comparison of Existing System Streamflow to the Oxbow/Backwater Marsh PISF. (High flow – days when flow is less than 3.51 cfsm during March – May, Low Flow – times when flow falls below 0.2 cfsm during May – September)

Representative Hydrograph	Reach 6,7 High Flow		Reach 6,7 Low Flow	
	Days	%	Days	%
Last five years	1,267	87.6	133	9.1
Wet three years	881	80.6	118	25.7
Average three years	908	83.0	60	13.1
Dry three years	990	90.0	318	69.3

Representative Hydrograph	Reach 8 High Flow		Reach 8 Low Flow	
	Days	%	Days	%
Last five years	174	11.9	250	17.1
Wet three years	185	16.9	56	12.2
Average three years	163	11.2	5	1.1
Dry three years	82	7.5	279	60.8

Environmental/Fish Habitat

Table 21 delineated the flow needs for the six bioperiods for fish and fish habitat. This table identified low flows as well as high flows. The low flows were compared against the representative hydrographs at Reach 2 (Upper Souhegan) and Reach 5 (Lower Souhegan) and the results displayed in Table 34. In a graphical sense, the hydrograph for the last 5-years and the Rare and Critical fish PISF are displayed in Figure 49. The upper half of Figure 49 shows the full range of flows, and the lower half of the figure focuses on just the low flows. It can be seen that the primary season for failure is in the summer (2001 and 2002). In the dry 3-year hydrograph (Figure 50), the river is unable to meet the needs of fish from June through December.

For the Lower Souhegan fish PISF there were more times when the river flow did not meet the PISF compared to the Upper Souhegan, primarily due to the late fall water needs (salmon spawning). Table 35 identifies the relevant statistics for the reference hydrographs. Figure 51 displays the low flow fish PISF comparison for the lower Souhegan River for the dry 3-year hydrograph.

Table 34. Comparison of Existing System Streamflow to the Fish PISF for the Upper Souhegan River. (Years – a water year in which one or more violations occurred, Number of Days – total days in the hydrograph when the PISF was not met, % - fraction of time represented by the previous column.)

Representative Hydrograph	Upper Souhegan Rare			Upper Souhegan Critical		
	Years PISF not met	Number of Days PISF not met	%	Years PISF not met	Number of Days PISF not met	%
Last five years	5	199	13.6	5	296	20.3
Wet three years	3	102	9.3	3	155	14.1
Average three years	2	8	0.7	2	49	4.5
Dry three years	3	418	38.1	3	467	42.6

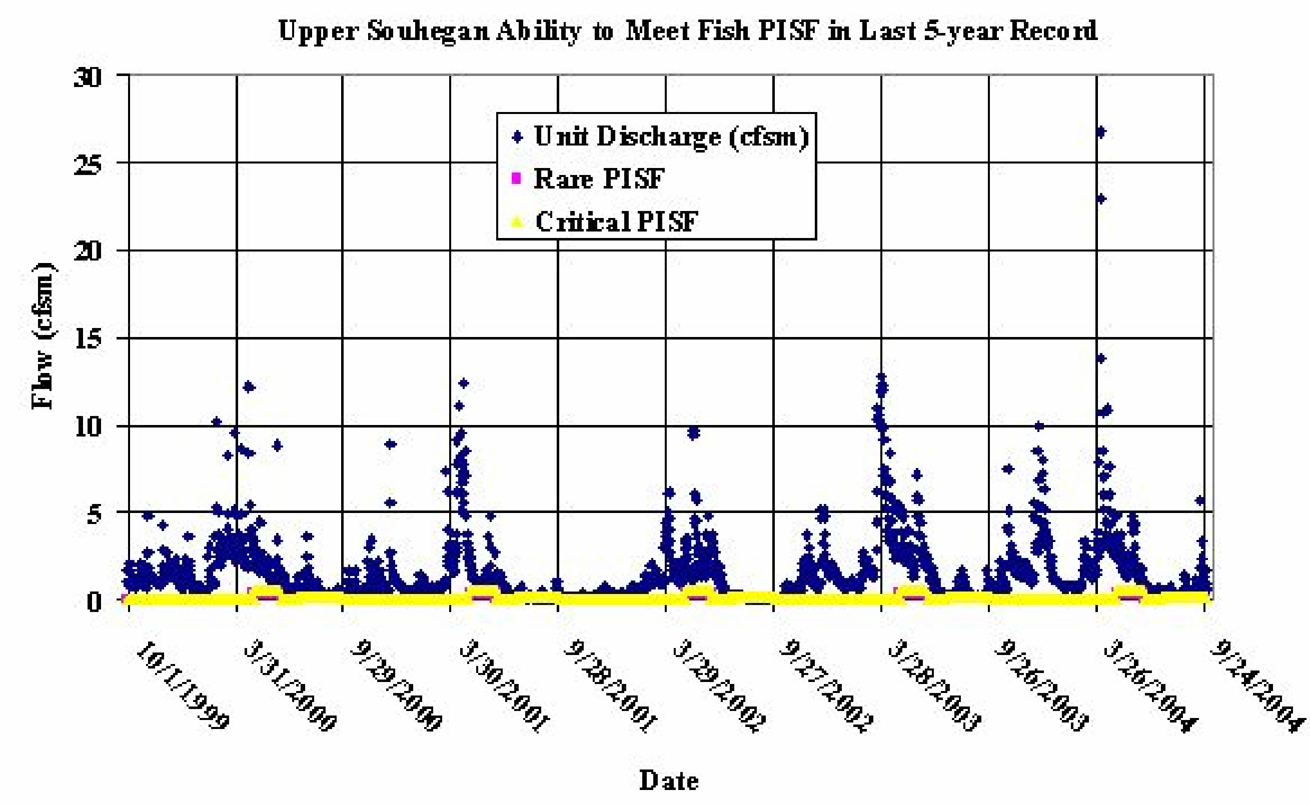


Figure 49a. Comparison of Fish PISF to Upper Souhegan River hydrograph for the last 5 years (magnified).

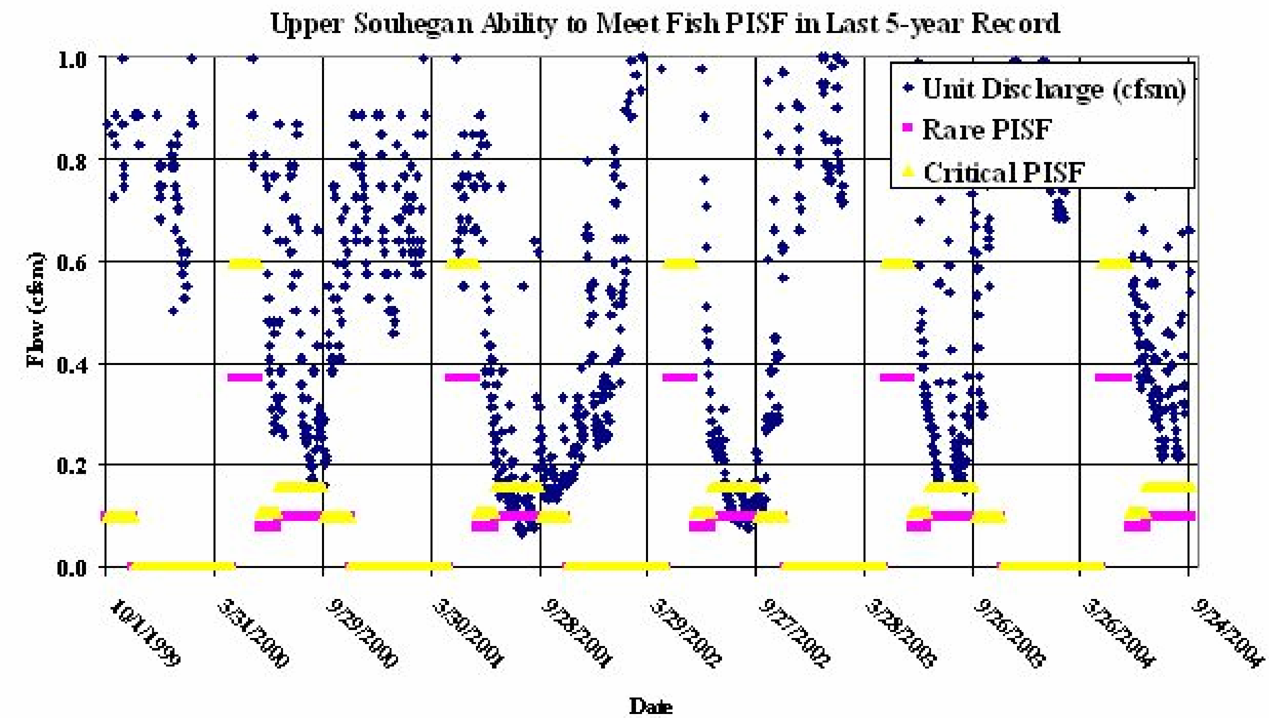


Figure 49b. Comparison of Fish PISF to Upper Souhegan River hydrograph for the last 5 years (magnified).

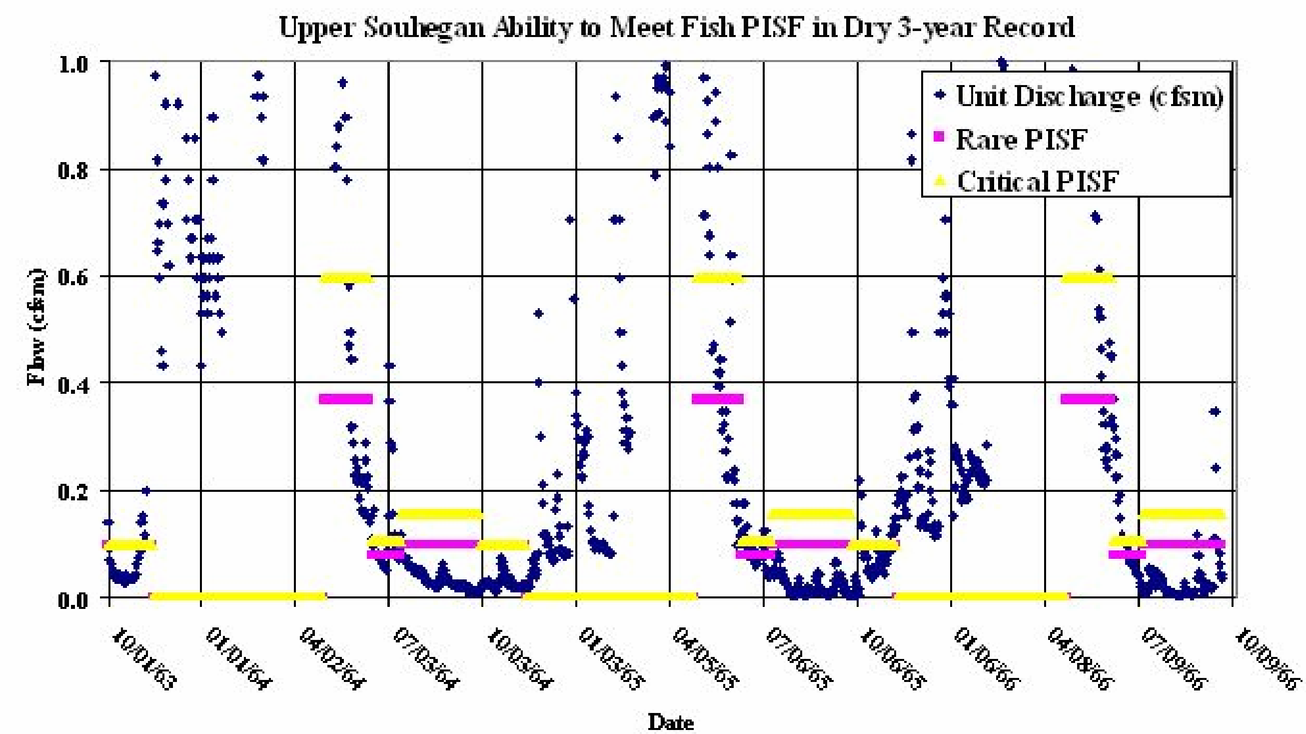


Figure 50. Comparison of Fish PISF to Upper Souhegan River hydrograph for the dry 3-year hydrograph.

Table 35. Comparison of Existing System Streamflow to the Fish PISF for the Lower Souhegan River. (Years – a water year in which one or more violations occurred, Number of Days – total days in the hydrograph when the PISF was not met, % - fraction of time represented by the previous column.)

Representative Hydrograph	Lower Souhegan Rare			Lower Souhegan Critical		
	Years PISF not met	Number of Days PISF not met	%	Years PISF not met	Number of Days PISF not met	%
Last five years	4	302	20.7	5	454	31.1
Wet three years	3	171	15.6	3	232	21.2
Average three years	3	123	11.2	3	202	18.4
Dry three years	3	603	55.0	3	662	60.4

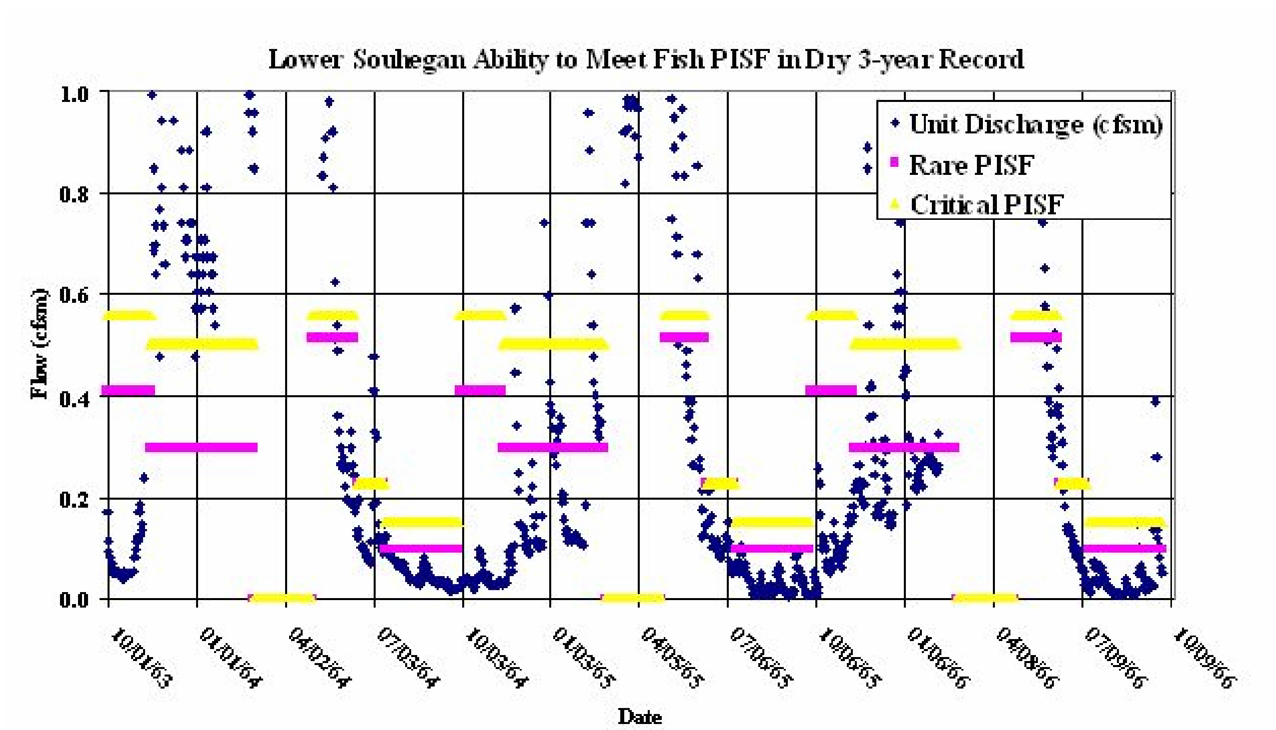


Figure 51. Comparison of Fish PISF to Lower Souhegan River hydrograph for the dry 3-year hydrograph.

There is also a high flow PISF for the Lower Souhegan River during the GRAF spawning period from June 15 – July 14. During this time, it is recommended that river flow not exceed the PISF (1.395 cfsm-critical, and 1.897 cfsm-rare). Table 35 displays the statistical summary for this PISF.

Table 36. Comparison of Existing System Streamflow to the GRAF Spawning, high flow PISF for the Lower Souhegan River. (Years – a water year in which one or more violations occurred, Number of Days – total days in the hydrograph when the PISF was not met, % - fraction of time represented by the previous column.)

Representative Hydrograph	Lower Souhegan Rare			Lower Souhegan Critical		
	Years PISF not met	Number of Days PISF not met	%	Years PISF not met	Number of Days PISF not met	%
Last five years	2	12	8.0	4	28	18.7
Wet three years	1	7	7.8	2	9	10.0
Average three years	1	13	14.4	3	18	20.0
Dry three years	0	0	0.0	0	0	0.0

III.) Water Quality Standards

As part of NHDES's biennial 305(d)/303(d) reporting to the USEPA (NHDES 2004), an assessment of compliance with water quality standards is made for all waters of the state. Although these reports indicate that the Souhegan generally meets most water quality criteria, there are specific non-compliance areas that are noted in both the 305(d) and 303(d) reports. The 305(d) report describes the extent to which water quality meets the designated use criteria while the 303(d) report lists waters that are impaired or threatened and require a Total Maximum Daily Load (TMDL) study.

First, all waters of the state are listed as non-supporting of aquatic life because of mercury. Second, portions of the Souhegan River above the confluence with Stony Brook are listed as non-supporting of aquatic life due to pH, aluminum, and macroinvertebrate and bioassessment criteria. In addition, a portion of this section is also listed as non-supporting of primary contact recreation due to E. coli bacteria. Finally, the lower section of the Souhegan River is listed as threatened for aquatic life due to copper.

For upper river listings, pollutant sources are listed as unknown. Most likely, the causes of non-compliance are related to atmospheric deposition, acid rain, and perhaps non-point sources. It is therefore concluded that existing water quality in the upper river is unrelated to streamflow, except for the 7Q10 PISF used to regulate the Greenville wastewater discharge, which itself appears to be unrelated to the non-supporting listings.

In the lower section of the Souhegan River where the State considers aquatic life to be threatened by copper, the source of copper is listed as "municipal discharges". The Milford NPDES permit has specific limits for copper in its discharge and these limits are by regulation based on 7Q10 flow. Since the only known threat to water quality in the lower river is related to municipal discharge, maintenance of the pollution abatement PISF of 7Q10 will be equally protective of water quality standards.

Review of the hydrologic data for the Souhegan River for the last five years indicates that streamflow as measured or estimated at the USGS gage dropped below the computed 7Q10 value of 13 cfs on only three days during the five-year period of evaluation– August 29, 30 and 31, 2001 – and only to 12, 11 and 12 cfs, respectively. Lower than normal flow conditions were experienced throughout New Hampshire in August 2001 due to below normal precipitation received during the late spring and summer. These data suggest that existing flow conditions overwhelmingly met the water quality PISF of 7Q10 flow during the 2000 - 2004 examination period. Even though there could have been a theoretical violation of water quality criteria for three days, Milford would have had to have been discharging at their maximum permit level and this combination of very low flow and maximum discharge seldom happens at most WWTP. Consequently, it is concluded that the existing Souhegan River system generally met the water quality PISF for the five year period of evaluation.

However, a 7Q10 flow event is by definition a 1 in 10 year event, so it is not unexpected that Souhegan flows during the five year study period did not fall below 7Q10. If a longer flow record were examined, lower flows would be more apparent and in very dry years, flows substantially below 7Q10 could be expected for an extended period of time. Furthermore, as evidenced by the presented hydrologic analysis, affected water users have historically (last five years) been reducing the streamflow in the lower Souhegan by 1 to 2 cfs or 10 – 15% of 7Q10, depending on location. Although streamflows will naturally fall below 7Q10 periodically, the data suggests that water users are likely causing streamflows to fall below natural 7Q10 levels more frequently than once every 10 years. Consequently, it is concluded that for the lower section of the Souhegan (i.e. from the Milford WWTP to the Merrimack River), the existing system does not and will not meet the water quality PISF and that mitigation should be investigated.

The use of concurrent flows in order to calibrate flows at the reaches of interest demonstrate that upstream of the Merrimack gage, the river flow for reaches 2 through 7 may have difficulty meeting the pollution abatement PISF of 0.067 cfsm. At a minimum, these results indicate the need for another real time stream gage in the upper watershed.

IV.) Discussion of how the proposed PISF values meet the criteria in RSA 483:1 and 483:2 and water quality standards

RSA 483:1 states the general instream flow policy for the state of New Hampshire, and that is for the, "…state to ensure the continued viability of New Hampshire rivers as valued economic and social assets for the benefit of present and future generations." RSA 483:2 goes on to frame the intent of the instream flow program, specifically that the New Hampshire Department of Environmental Services, "…rivers management and protection program shall complement and reinforce existing state and federal water quality laws, and that in-stream flows are maintained along protected rivers, or segments thereof, in a manner that will enhance or not diminish the enjoyment of outstanding river characteristics." In addition, "…the scenic beauty and recreational potential of such rivers shall be restored and maintained, that riparian interests shall be respected…"

The PISF values that have been developed in the performance of the present study were developed based upon the needs of each IPUOCR. These needs can be synthesized into one figure each for the upper and lower portions of the river. In order to perform this synthesis, all PISF values are compared for each Julian Day. For the low flow requirements, the highest of all IPUOCR PISF values is the controlling PISF: by meeting this PISF, then all other IPUOCR low flow PISF are met. When this is done, the first result is that the recreation PISF of 4 cfsm in the upper Souhegan River controls. As presented, this is a PISF for recreational boating on the river. There is not existing adequate water storage or control to meet this PISF for long durations by water management strategies, so it is not included in the synthesized PISF.

Another human-related PISF in the Upper Souhegan River is for hydropower (0.7 cfsm). Since all hydropower facilities on the river are historically run of river operations, this PISF is not included in the synthesized river system PISF.

The pollution abatement PISF controls in the Upper Souhegan from November 14 through April 30 (0.067 cfsm) and in the lower Souhegan for all of March and April. Although it may be possible to control storage to meet this PISF, it is not included in the synthesized PISF, since it is primarily related to waste water treatment plant design and permitting. However this PISF will be considered in the management plan, especially strategies to meet pollution abatement goals in the overall strategy of flow management.

The resulting synthesized PISF are therefore exclusive of the human PISF (recreation, hydropower, and pollution abatement). Figure 52 depicts the synthesized PISF for the Upper Souhegan River. From November 15 through April 30, there is no minimum PISF. For the remainder of the year, the fish PISF control. Figure 53 depicts the synthesized PISF for the Lower Souhegan River. In the case of the "rare" low flow PISF, for December, January, and February, the PISF is controlled by the wood turtle PISF. In March and April there is no PISF. From May 1 through November 30, the fish PISF controls except for the period of July 15 to August 20, when the Fowlers toad PISF controls. In the case of the "critical" low flow PISF, for December, January, and February, the PISF is controlled by the wood turtle PISF.

In March and April there is no PISF. From May 1 through November 30, the fish PISF controls.

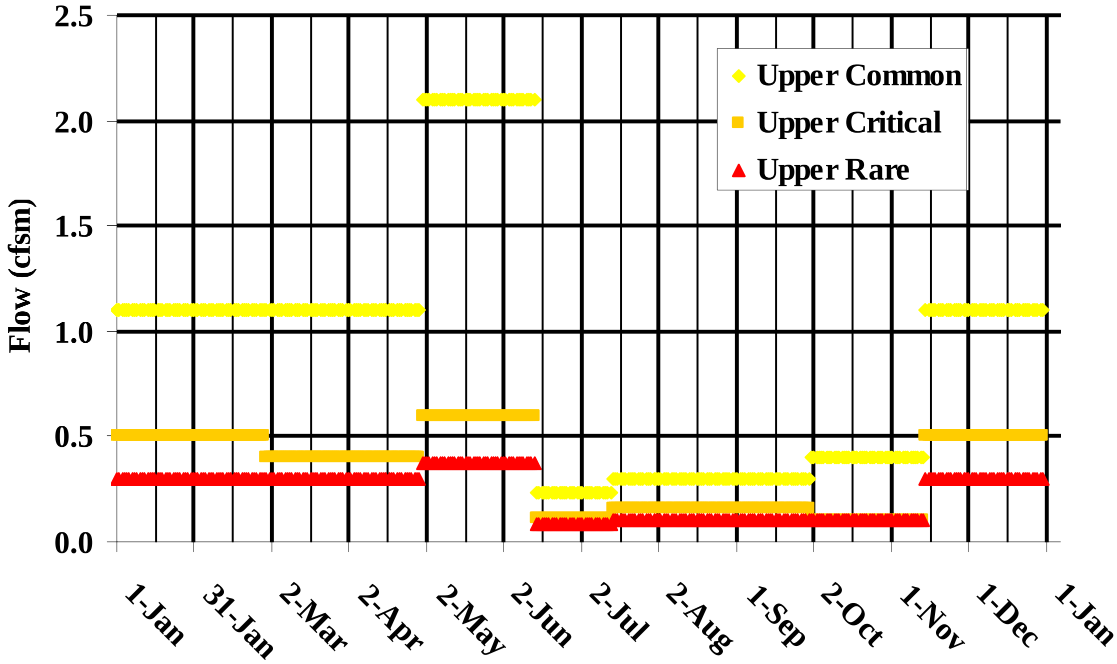


Figure 52. Synthesized PISF for the Upper Souhegan River.

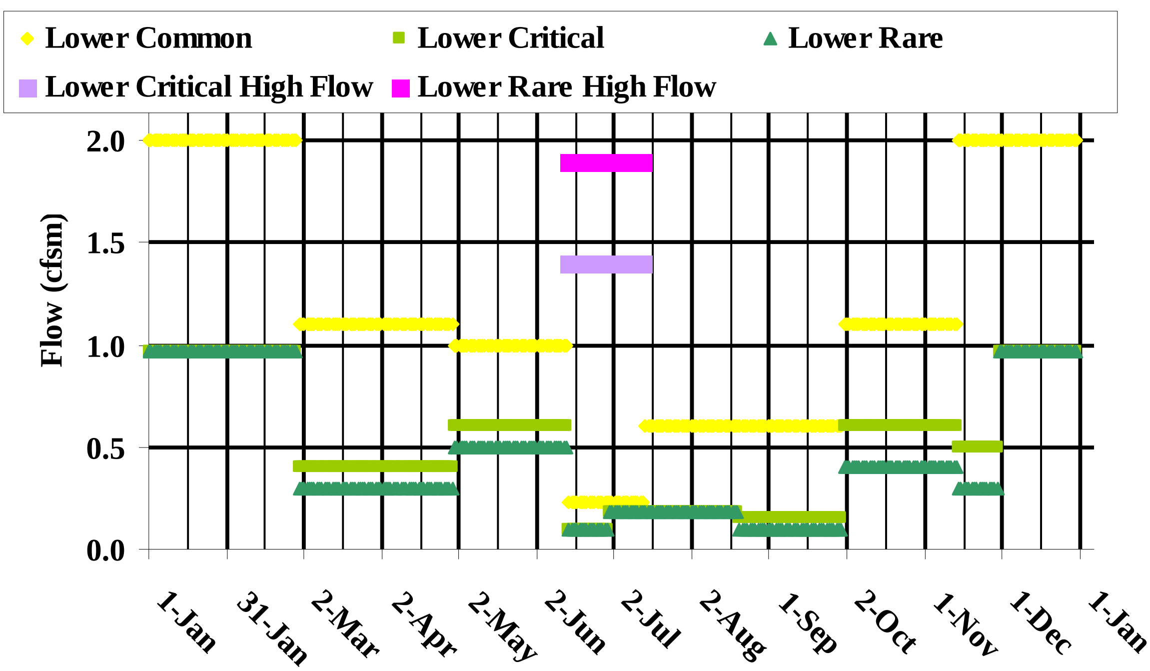


Figure 53. Synthesized PISF for the Lower Souhegan River.

It must be recognized that many of these ecosystem PISF are not stand alone criteria: when river flow falls below the PISF, this does not mean that the PISF are not met. Many of these ecosystem PISF also have an attendant duration: when river flow falls below the recommended PISF for the durations of time that were described in section IX - Environmental/Fish Habitat (Table 21), then the PISF is not met. Therefore the first use of the PISF, in a management sense, is to observe when the river is approaching the PISF (for example within 10% of the PISF). When the river flow is at 110% of the PISF, river flows and weather patterns need to be monitored on a daily basis. When river flow falls below the PISF, then the system is poised for management strategies, and at the time that the PISF flow and duration are both met, management strategies need to be implemented.

A hidden issue is that these PISF were developed from the flow duration data at the USGS gage in Merrimack, NH. This data set is the average daily flow that is developed from 15-minute observations. As such, it is hypothetically possible for a user on the Souhegan River to temporarily divert the entire river flow for a brief period. In this scenario, although the average daily flow meets the PISF criteria, for the brief period of the large diversion, the PISF is not met. In another scenario, the diversion drops the flow below the PISF for days, but not as long as the recommended durations in Table 21. There are a few manners to address this type of scenario. One manner is to use the established PISF as real time measures; in this case, diversions such as that portrayed in these hypothetical scenarios would be required to cutback if the flow in the Souhegan River fell below the PISF: this is a management strategy. This will require real time monitoring of the river, but it should also include an effort by all towns in the watershed to critically review proposals of this nature and enforce the PISF at the local level.

Another management strategy for dealing with large yet short duration diversions is to only allow them to operate within the natural variability of the natural system. In the natural system, recession flows are gradual. A very large diversion however could dramatically reduce flows over a very short time period. Therefore in this case a measure that could be used to regulate the hypothetical large diversion is by its effect on the rate of flow recession, for example limiting the withdrawal rate to no more than 1 cfs per hour of change to river flow: If the requested diversion were to be 5 cfs, then this diversion would require at least 5 hours to ramp-up to its full withdrawal request. Since the PISF and the hydrology were all based on the flow per watershed area (cfsm), this "ramping" measure was similarly developed (cfsm/hr). Over the course of this study, the 15-minute USGS data from the Merrimack gage were saved to file (they are only available from the USGS web site on a sliding 31-day window that starts at the present day). The flows were then converted from cfs to cfsm. The common and rare PISF were then studied: for common flows, the real time data was cropped for only continuous flows between 1.7 to 0.57 cfsm and for the rare flows, the real time data was cropped to continuous flows between 0.33 to 0.18 cfsm. The reason for cropping flows into hydrograph segments that fit into the ranges was to meet the hypothetical scenario where the average daily flow met the PISF, yet short duration diversions could temporarily drop the river flow below the PISF. The rate of change of flow (cfsm) per hour was then calculated by looking at the difference in flow over various time steps (1, 2, 4, 6, 8, 12, 24 hours). As would be expected, because the focus here is on the low flow end of the spectrum, the majority of natural recession rates are less than 0.003 cfsm/hr, whether flow averaging from 1 to 12 hours. To use this measure, one must be monitoring the real-time recession rate, or towns and the State would use this measure when they consider development proposals.

The other method of addressing potential scenarios that could skirt the intent of the PISF detailed in Table 21 is to create PISF that specifically address all such hypothetical scenarios. The sentiment is that by overprescribing the PISF, it makes the PISF less adaptable to future conditions and states. In addition, to create PISF to address the many possible diversion scenarios along the river would make the PISF themselves cumbersome and overly complicated. Therefore the selected manner of addressing water uses (present and future) is left to the Water Management Plan. The PISF prescribed in Table 21 are those flows that best protect all water-dependent IPUOCR. Such PISF may appear to allow loopholes such as the identified hypothetical scenarios; however the management plan will address these scenarios.

V.) Preliminary Determination of Designated River Reaches

Although this report has not delved into water use and management, it is clear from the water use records that the Souhegan River enjoys a relatively small percentage of diversions. At very low river flows, these diversions comprise a significant fraction of the total flow, however a large percentage is believed to be returned to the river in some form (irrigation return flows, commercial return flows, ground water, leach field systems, and as treated waste water effluent).

There are a substantial number of very small flood control reservoirs in the system, and these have most likely had the effect of reducing flood peaks from the lower frequency flood events (say less than the 10-year event) as well as have historically buoyed low flows. A severe penalty of these reservoirs appears to be the very high water temperatures in the system, especially in the upper watershed. These temperatures prohibit a viable cold water fishery and warrant serious consideration in the management plan, for if they are not addressed, no amount of additional water at low flow times will revive the cold water fishery.

Given these constraints, the natural flow paradigm is not that far from the present flow conditions of the river (See Appendix 3: Indicators of Hydrologic Alteration). In general, all but the fish PISF are regularly met. Figure 54 displays the daily flow frequencies for the Souhegan River at the USGS Merrimack gage. On May 2, for example, 95% of the time the flow exceeds 1 cfsm, 75% of the time it exceeds 1.6 cfsm, etc. This statistical summary of daily flows is then compared to the PISF (Figures 55 and 56).

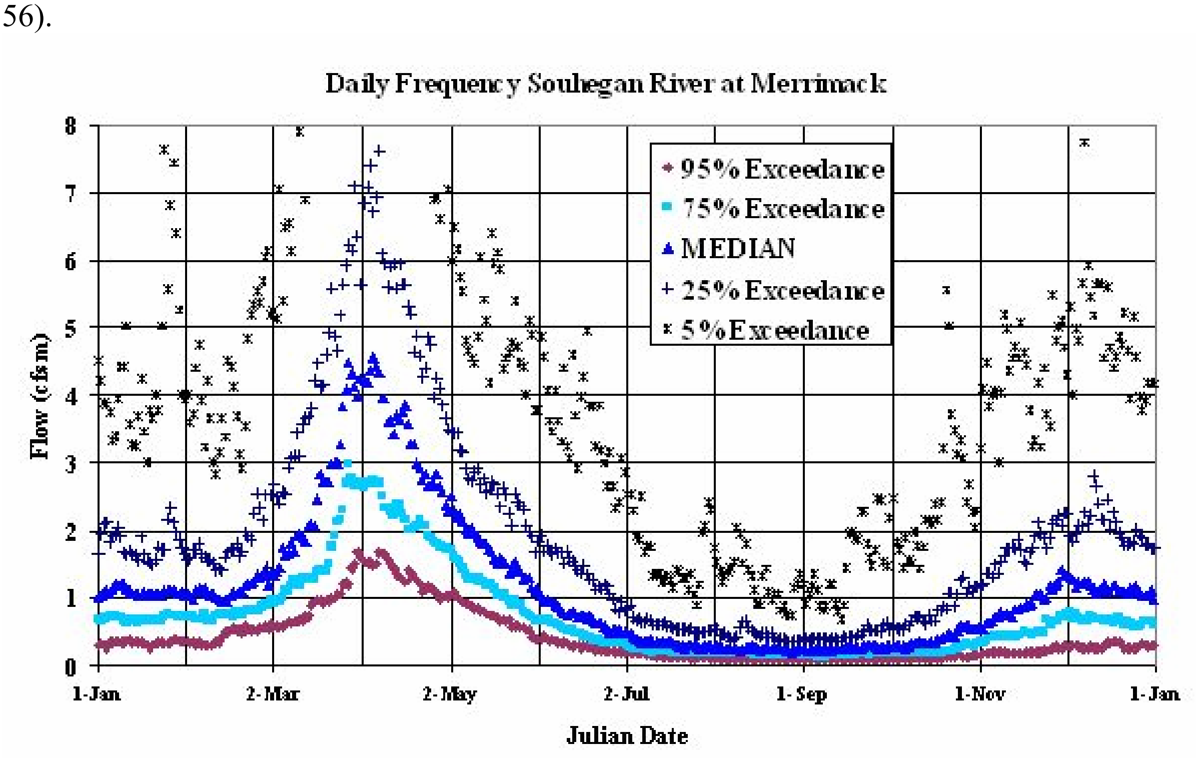


Figure 54. Daily flow frequency statistics for the Souhegan River (based on the USGS gage in Merrimack).

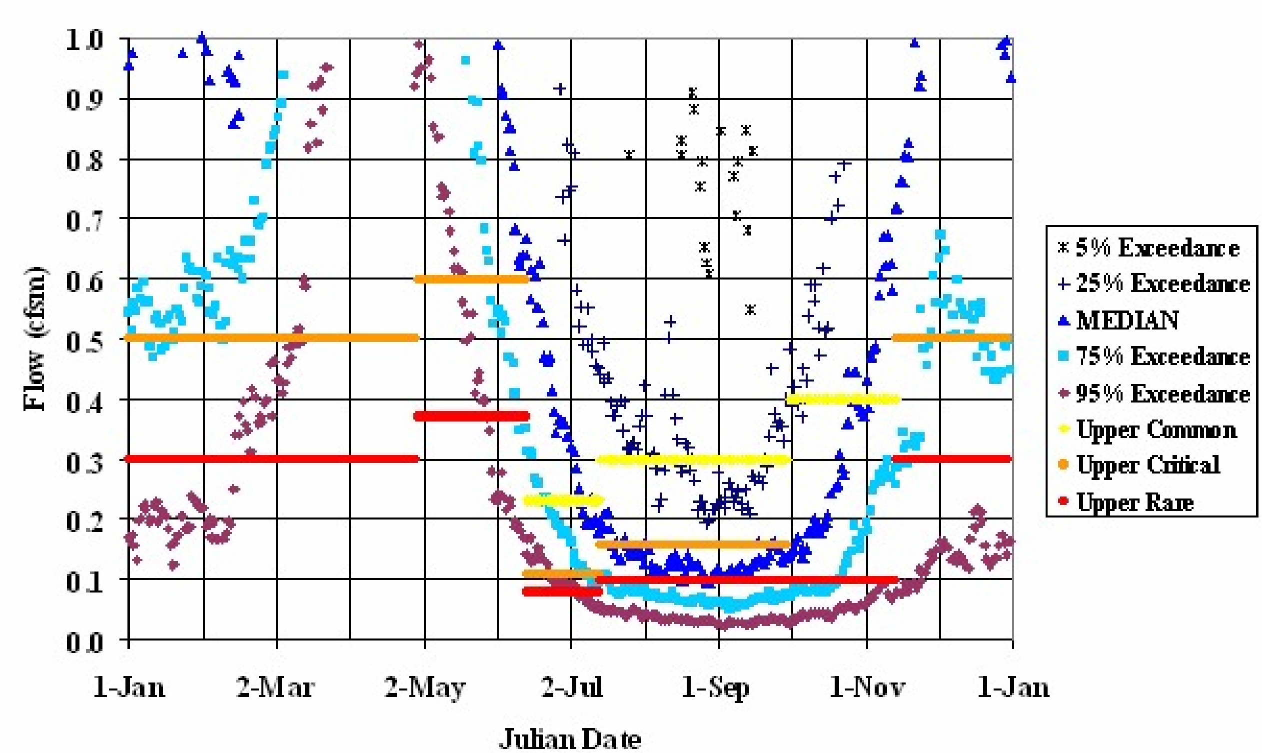


Figure 55. Comparison of Upper Souhegan River instream flows to daily flow frequencies

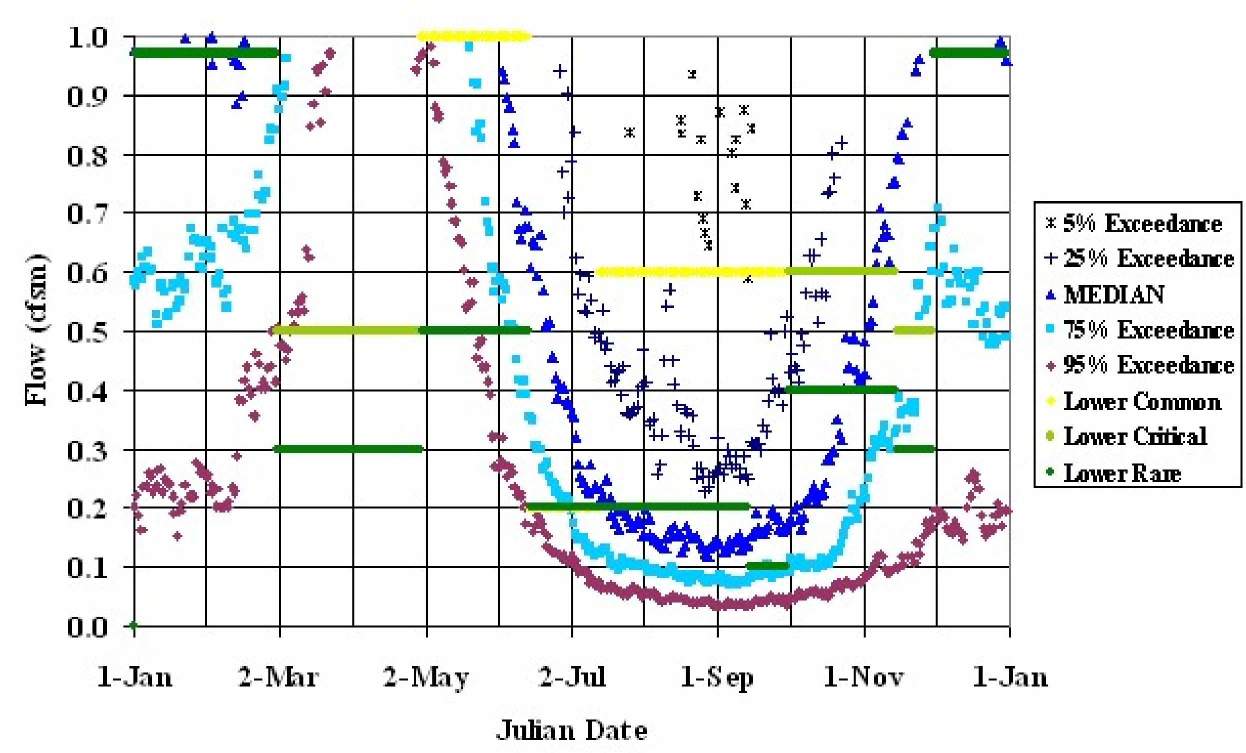


Figure 56. Comparison of Lower Souhegan River instream flows to daily flow frequencies.

In Figure 55, the Upper Souhegan PISF are compared to the daily flow frequencies developed for Reach 2. From mid-November to mid-May, the system always meets the PISF. From mid-May to mid-June, shad spawning PISF controls, and the system starts to exhibit an inability to meet the PISF. However, remember that this is not considering the duration that the flow does not meet the PISF, which is the other important variable. From mid-June to mid-July, the PISF is now controlled by the GRAF spawning, and in general the river meets these needs. From mid-July to early October the PISF is controlled by fish rearing and growth, and here the river has trouble meeting the PISF. For most of this period, the critical PISF exceeds the median river flow and the rare PISF exceeds the flow that is exceeded 75% of the time (meaning that 25% of these days, on average, the river is flowing below this PISF). As a measure for the management plan, an increase to the river flow at this location by 0.05 cfsm equates to 3.2 cfs, or roughly 6.4 AF of storage per day.

In the lower Souhegan River (Figure 56), from the start of December to the beginning of March, the river appears to have difficulty meeting the PISF, since the PISF is greater than the 75% exceedance flow. However, the controlling PISF during this time interval is for the wood turtle, and the PISF is defined such that the December through March flows not go lower than the average November flow. In the simplification and synthesis of all the PISF, the average November flow was identified as this PISF. In reality, if one looks at the median daily lower Souhegan flow in Figure 54, it is apparent that normally the river flow is higher at the end of November and slowly declines though mid-February. This would be the typical seasonal recession for the river. For the management plan, every year, the average November flow should be used as the PISF measure for flows in December through the end of February. The overwintering flow for fish during this same time period is 0.3 cfsm, and the river meets this about 90% of the time. The lower Souhegan meets the PISF in March and April. From mid-May to mid-June, the shad spawning PISF controls, and the river flow only meets this 50-75% of the time. Again, in an episodic fashion, real river flows in which there are storm events will satisfy these spawning needs. This GRAF spawning PISF (mid-June to mid-July) is also only met 50 – 75% of the time. From mid-July to the end of September, the rearing and growth PISF controls, and the river flow meets this flow requirement less than half the time. October into mid-November is the salmon spawning PISF, and more than half of the time the river cannot support the PISF.

When looking at the Dry 3-year record (Figures 57 and 58), it can be seen that during some parts of the year, flow exceeds the 75% exceedance probability, however, in the period June through February the following year, in the two middle low flow periods, the river flow was well below the 95% exceedance curve and cannot meet the PISF is such an extreme low flow epoch.

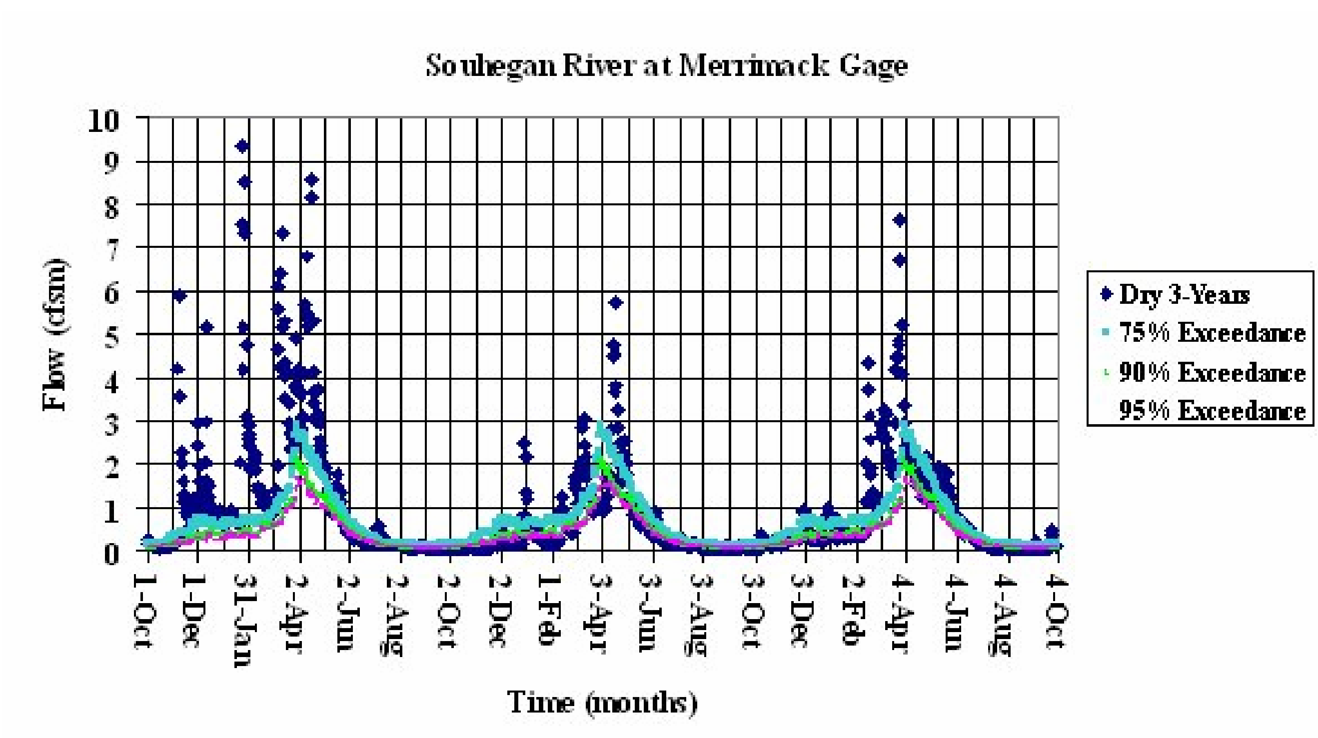


Figure 57. Comparison of Dry 3-Year hydrograph to daily exceedance frequencies – full scale.

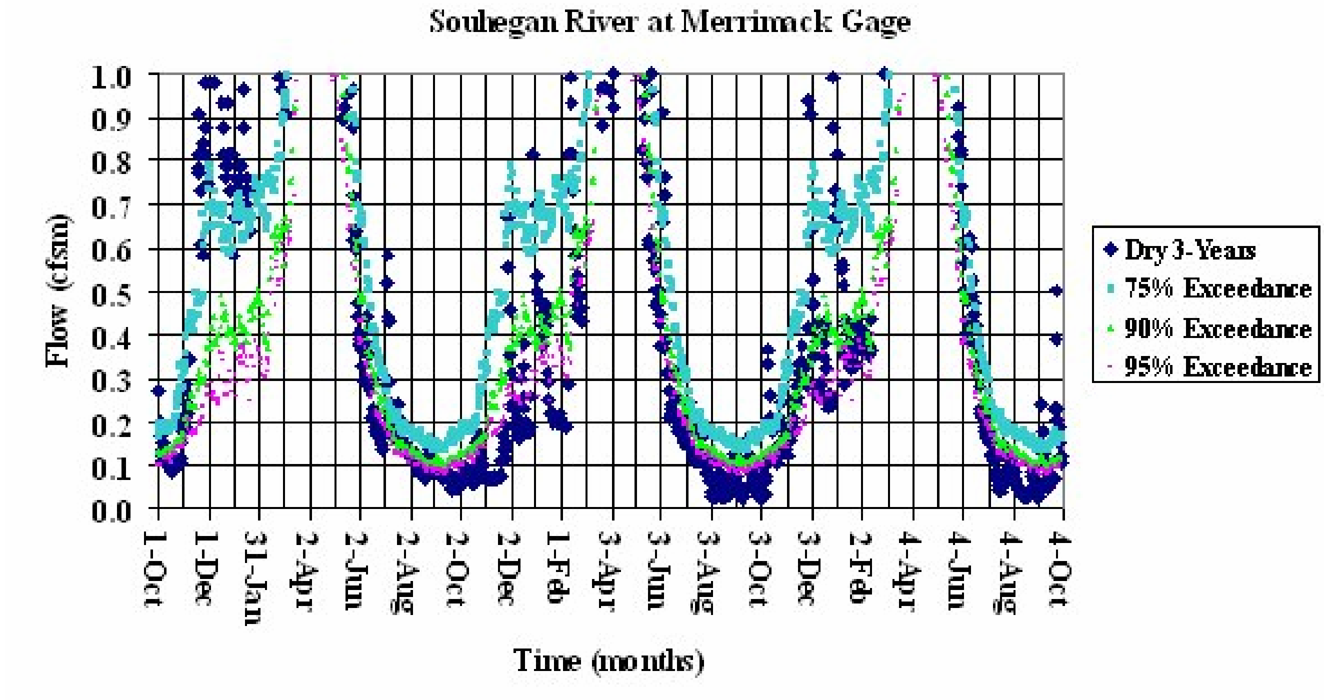


Figure 58. Comparison of Dry 3-Year hydrograph to daily exceedance frequencies – magnified scale.